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TRANSACTIONS
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ADVANCES IN ENGINEERING

RESULTS of tests recently completed on full-sized steel columns at the Bureau of Standards show that under present specifications differences in the physical properties of the material entering into sturdy columns produce greater variation in the column strength than all the differences in type of construction.

This work was conducted in co-operation with several large steel companies who furnished more than 130 tons of steel meeting specifications under which structural steel is usually purchased. The steel was fabricated into 69 columns having H-shaped sections and of five different types of construction. The finished columns were tested to destruction in the 10,000,000-pound testing machine of the Bureau. Likewise, over 1,000 test specimens were cut from the columns and subjected to chemical analyses and physical tests to determine as accurately as possible the properties of the steel from which the columns were made. All of the material met the specifications under which it was furnished, but differed greatly in tensile yield point.

Although much work has already been done on columns, the subject of column strength and method of design, especially in large sizes, is still a matter for so much discussion that the additional data which these tests have furnished will be of great value to engineers and to the public safety and human welfare. It is hoped that this work will be continued.

PROGRESS

THE many commendatory statements reaching the National Office relative to the A. S. S. T. handbook should be a source of gratification to all members of the Society. The data sheets that have so far been issued represent the composite work of almost one thousand members of the Society. These persons have served as members of committees, reviewers, critics, suggestors and each in

his own way has been responsible for the splendid results accomplished. Not only is the demand for the sheets already issued growing steadily in the iron and steel industry in America, but the requests from foreign countries have been increasing rapidly and overtures have been made for the translation of the handbook into foreign languages.

When one takes the time to survey the progress made with the handbook in the short period of three years, one observes a record of steady production of high grade material. With the exception of the first few sheets mailed in December, 1923, the remainder of the 400 sheets have been prepared and forwarded to the members under the careful and conscientious direction of J. Edward Donnellan, secretary of the Recommended Practice Committee under whose jurisdiction is the final approval of the sheets. Mr. Donnellan has received the most cordial co-operation from the members of the Society and that has made possible the outstanding achievement of this worth while undertaking.

Sometime ago it was decided to extend the scope of the A. S. S. T. data sheets which have dealt exclusively with ferrous metals, to include the nonferrous metals. The Institute of Metals was invited by the A. S. S. T. to undertake the preparation of these data sheets. The Institute accepted the responsibility and a committee has been appointed to handle this work consisting of R. S. Archer, T. S. Fuller, C. H. Mathewson, Jerome Strauss and F. L. Wolf. The first of the nonferrous data sheets will be forwarded to members within the next 60 days and so with the comprehensive scheme outlined by this nonferrous committee, it will not be very long until our members have been provided with the A. S. S. T. handbook not only on ferrous but also nonferrous material. The officers and directors of the A. S. S. T. appreciate the response and co-operation of the membership on the work of the handbook and feel confident that the members take a just pride in its progress and accomplishment.

Future Meetings

SPRING SECTIONAL MEETING—Milwaukee, May 19-20, 1927.

ANNUAL CONVENTION AND EXPOSITION—Convention Hall, Detroit, September 19-23, 1927.

THE IMPORTANCE OF CEMENTITE

By Robert G. Guthrie

Abstract

The author calls especial attention to what he believes to be some basic and well-known points which are of vital importance when anticipating the behavior of articles manufactured from straight carbon steel. These phenomena, he feels, when applied along logical lines will be a reliable aid in the heat treatment of material similar to that discussed in this paper.

In his summary, the author states that he is of the opinion that the condition of the cementite is of the utmost importance, and that in low carbon steels which are not to be subjected to hardening, it is desirable that the cementite be in spheroidal condition but that in high carbon steels which are to be subjected to hardening it is desirable to have the cementite in lamellar form. His reasons are clearly enumerated.

THE title of this paper should be amplified to read "The importance of the 'Condition' of cementite." The various facts brought out should not be looked upon as laws relevant to the subject, but rather a simple and practical set of observed phenomena which, if applied along logical lines, will be a reliable aid in the heat treatment of material similar to that discussed. Furthermore, the facts noted will be found to materially aid in the interpretation of photomicrographs of similar materials, as well as their physical, thermal, and chemical behavior.

The first material under observation is an hypoeutectoid steel of from 0.09 to 0.15 per cent carbon. Fig. 1 is a billet suitable for wire drawing and is of the so-called effervescing or rimmed steel variety. Inasmuch as the dark center is characteristic of this type of steel it is necessary to find out what it consists of and why it does not etch like the adjacent rim. Apparently this point has been the subject of much controversy in the past with the consequence that many ideas have been advanced as to its chemical and physical nature. The reason for its existence has by some investigators been accredited to sulphur segregation. True, if a sulphur

A paper presented before the eighth annual convention of the Society, Chicago, September 20 to 24, 1926. The author, Robert G. Guthrie, is consulting metallurgist, Peoples Gas Light and Coke Company, Chicago.

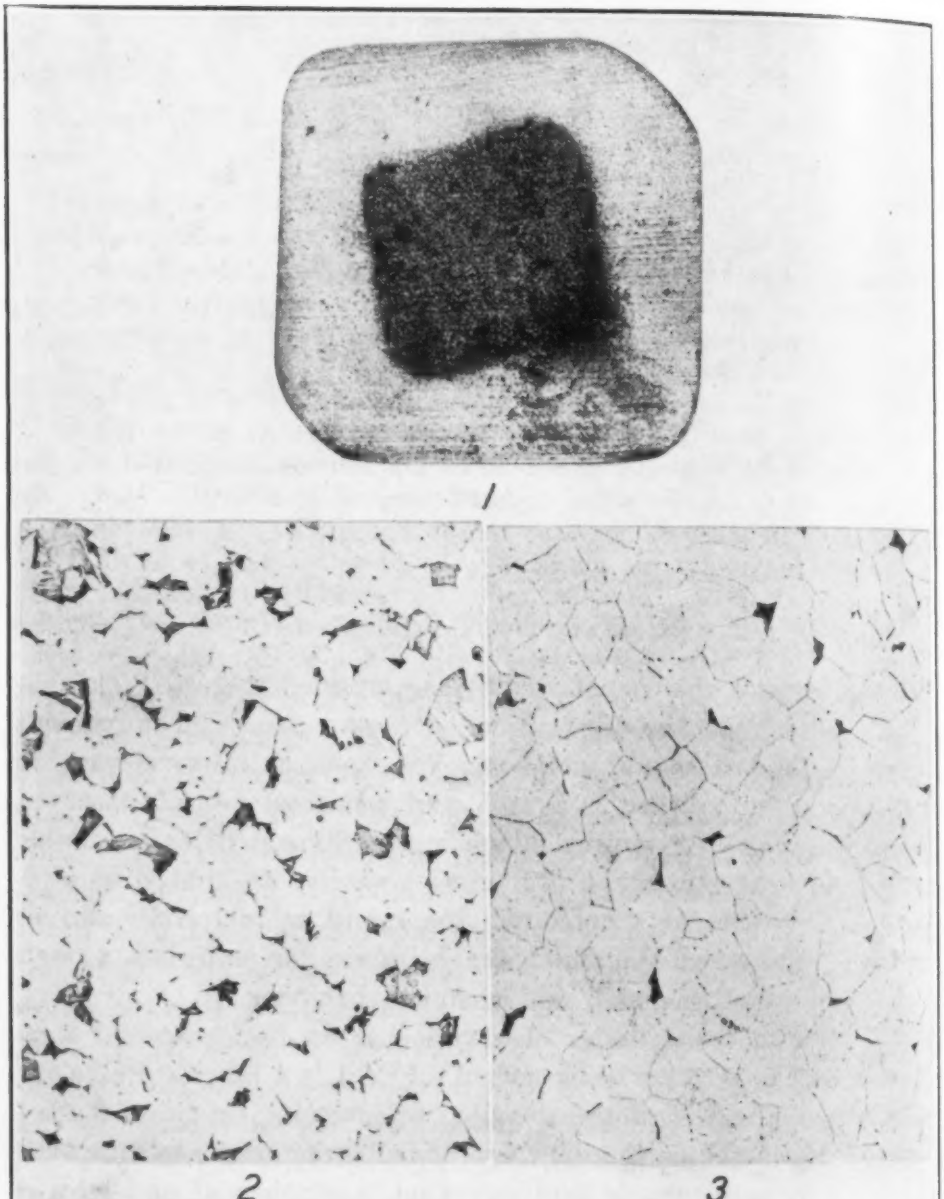


Fig. 1—Photograph of Billet Suitable for Wire Drawing of the So-called Effervescing or Rimmed Steel Variety. Chemical Analysis of Rim and Core Varied Only Slightly. Fig. 2—Photomicrograph of Core Showing Apparently Normal Carbon Steel Having an Appreciable Amount of Pearlite. 100x. Fig. 3—Photomicrograph of Rim Showing Relatively Few Pearlitic Patches but Large Amount of Cementitic Globules or Spheroids in Very Small Size in Ferrite in Grain Boundaries. 100x.

print is made of a similar section it will apparently show a complete outline of the core or dark area high in sulphur. As a general rule if the outside rim is machined away and a tensile test bar made of the core, such a bar will show higher tensile strength

with less ductility than one made from the material in the rim. These facts will naturally lead to the conclusion that two steels of different chemical analysis were present. Such, however, is not the case.

The billet shown in Fig. 1 was carefully analyzed in the rim and in the core, but the slight difference did not account for the great difference in physical properties and microscopic analysis. A microscopic study of the condition of the cementite, however, did reveal a logical basis for the widely different physical properties between the rim and the core, although their chemical analysis varied slightly.

Fig. 2 is a photomicrograph of the core and shows an apparently normal carbon steel having an appreciable amount of pearlite. Fig. 3 is a photomicrograph of the rim showing relatively few pearlitic patches but a large amount of cementitic globules or spheroids of very small size in the ferrite grain boundaries.

Upon examination at higher powers of the microscope it is revealed in Fig. 4 that the pearlite of the core has cementite of the lamellar or striated variety. Fig. 5 reveals the cementite in the ferrite grain boundaries as globular which is typical of the case or rim. Fig. 6 which is also typical of the rim and shows the globular or spheroidal cementite outlining a ferrite grain.

Photomicrographs Figs. 7 and 8 show the line of demarcation between the case and the core in transverse and longitudinal section respectively. It may be noticed that apparently the core contains more carbon than the rim. This, however, is not the case as the carbon contents are nearly the same.

Fig. 9 again shows the pearlitic patches common to the core which have finely striated or lamellar cementite. Fig. 10 shows free cementite in the rim which has formed into streamers or masses which have not formed the conventional pearlite which would be expected of a material of this type.

It has been shown that the core possesses the following physical properties in comparison to the rim: higher tensile strength, with a greater hardness, less ductility, less resistance to corrosion, and more rapid solubility in etching reagents. It will be noted that the more rapid solubility of the core in acid is accountable for the core showing apparently higher sulphur content when a sulphur print is made. The greater solubility of the core is accounted for

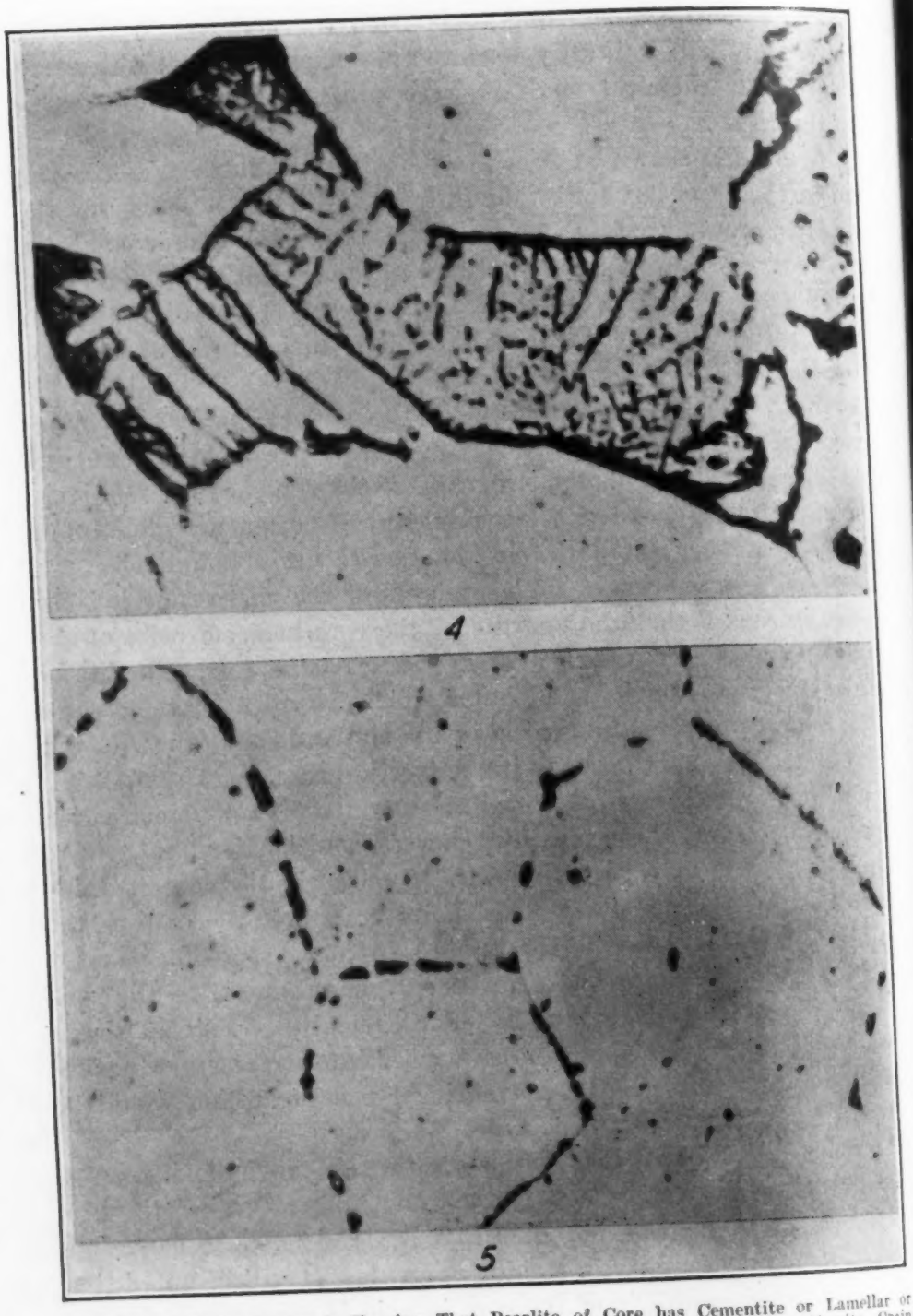


Fig. 4—Photomicrograph Showing That Pearlite of Core has Cementite or Lamellar or Striated Variety. 1500x. Fig. 5—Photomicrograph Showing Cementite in Ferrite Grain Boundaries as Globular. Typical of Case or Rim. 1500x.

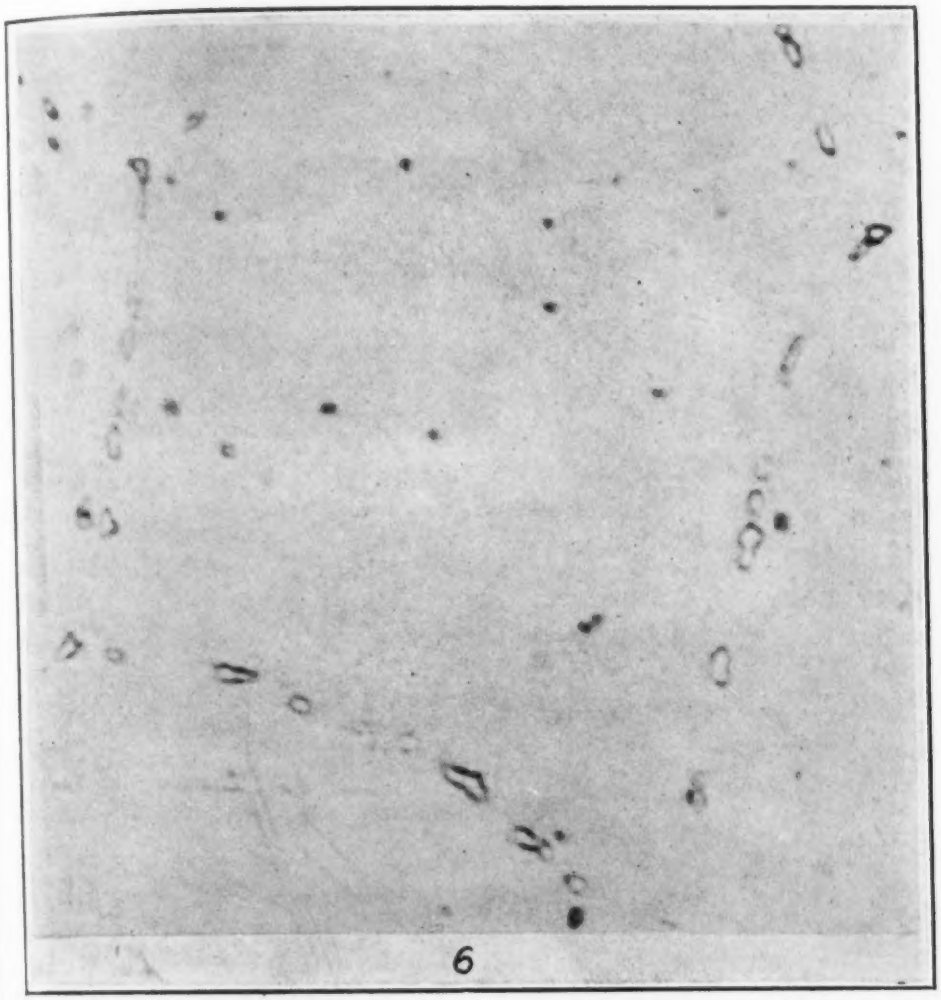
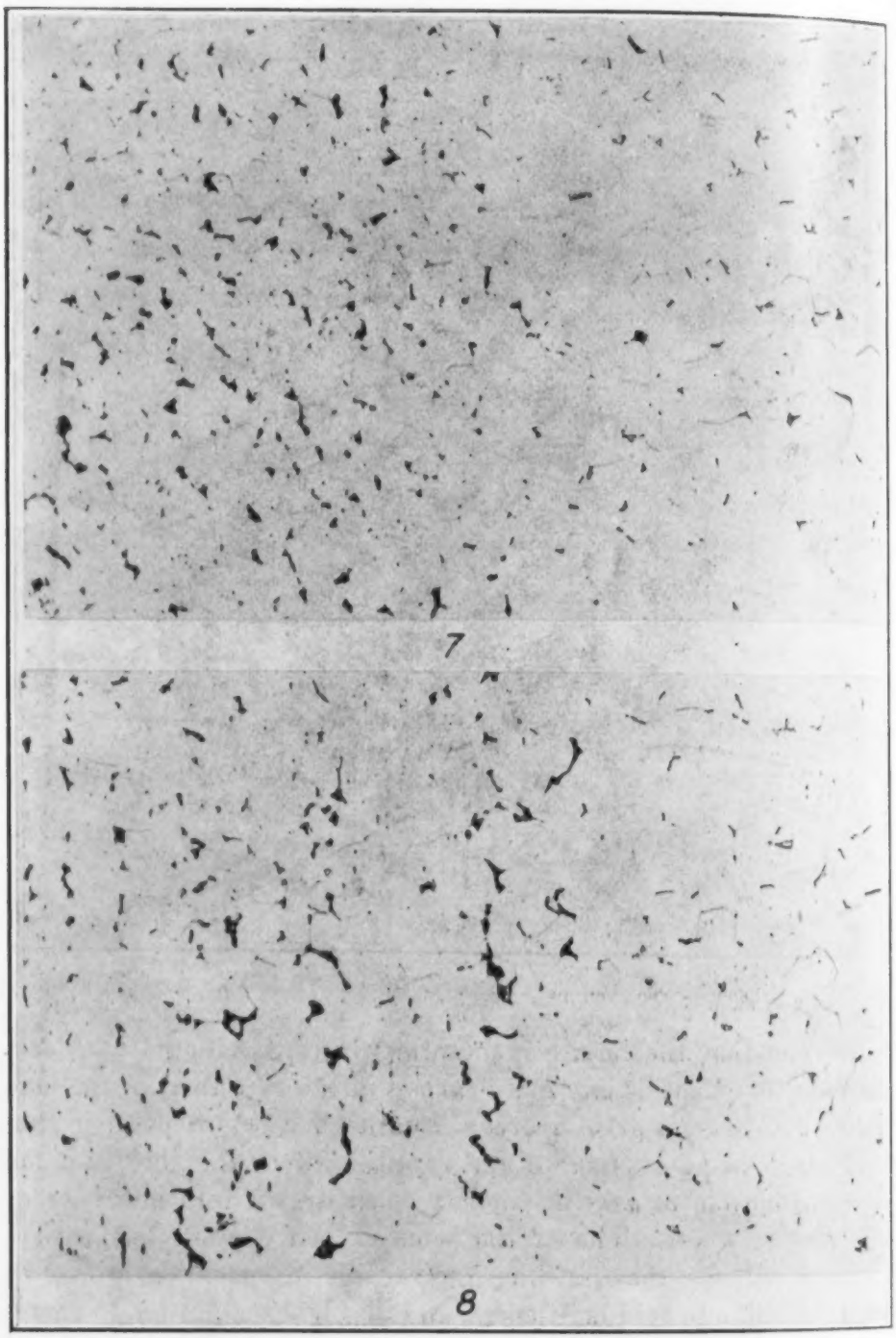


Fig. 6—Photomicrograph Showing Globular or Spheroidal Cementite Outlining a Ferrite Grain. 2350x.

by the fact that the ferrite is more highly contaminated with carbide, not that there is any more carbon in the core than in the rim, but that it covers a greater area. Another important point is that steel which has a surface of the type shown in the core is much more susceptible to acid brittleness when drawn into fine wire or thin sheets; whereas one of the same carbon content but with a surface similar to the rim, i. e., the carbide in spheroids, would be less susceptible to acid brittleness, and also less susceptible to corrosion. In electroplating, a steel having a surface similar to the core would not take as uniform a deposit and the deposit would not adhere as tenaciously as one having a surface like the rim.

Photomicrograph Fig. 11 is that made from a specimen of



Figs. 7 and 8—Show Line of Demarcation Between Case and Core in Transverse and Longitudinal Section Respectively. 100x.

killed steel of about 0.09-0.15 per cent carbon. The killed steel billet has this structure throughout its cross-section and the

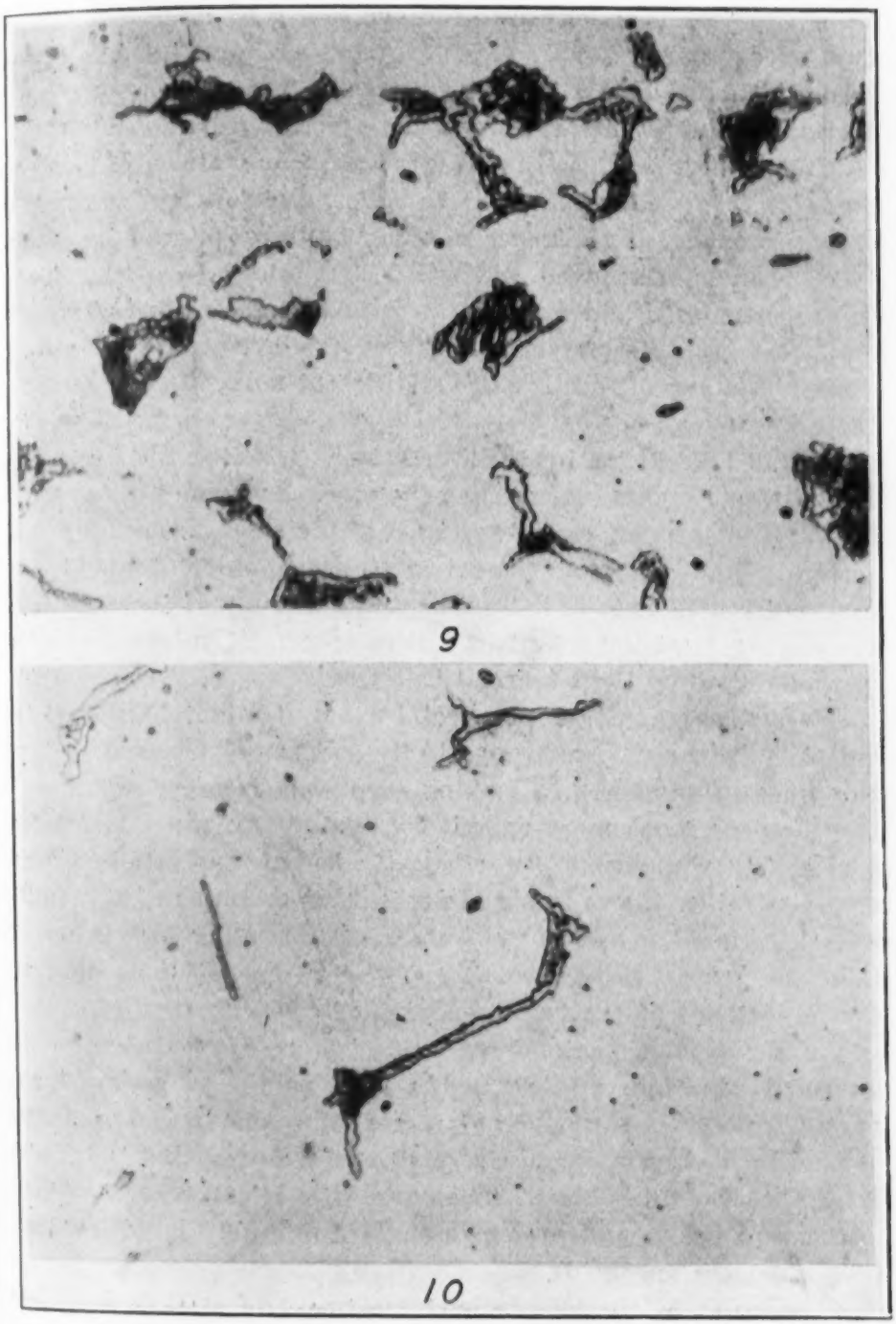


Fig. 9—Photomicrograph Showing Pearlitic Patches Common to Core Having Finely Striated or Lamellar Cementite. 1500x. Fig. 10—Photomicrograph Showing Free Cementite in Rim Which Has Formed Into Streamers or Masses. 1500x.

similarity of this structure to the one shown of the core in Fig. 2 is at once apparent. Fig. 12 is of an area of Fig. 11, but at higher magnification. This steel has practically the same physical and thermal properties as the core in the preceding discussion.

An interesting point to note is that a comparison of hardness readings between the core and the rim as shown in Fig. 1 gives the same percentage of difference as a great number of readings of surface hardness of rimmed and killed steel which have been drawn to the same gage and are of approximately the same carbon content. As an example, 266 Rockwell readings were made upon some 30 samples of rods from four different mills. In each instance there was an average hardness of 10 points lower on the B-scale for the rimmed steel than for the killed steel. Likewise the rim of Fig. 1 was 10 to 15 points softer than the core. So great a difference in the physical properties of two steels of the same chemical analysis certainly indicates that these two steels should and would have different reactions to heat treatment and a study of these reactions reveals the most important as well as the most interesting information regarding their thermal behavior.

Before going into this subject further it might be well at the outset to draw a simple analogy to the solution or miscibility of one substance in another. In making soap suds as everyone knows it may be done much more quickly by heating the water as the first step and then slicing or converting the bar of soap into thin flakes or plates rather than placing the entire bar or chunk of soap in the water. While this example is homely it may well be used to explain the time element in heat treatment of steel as well as to illustrate the importance of the condition of the cementite.

Fig. 13 is a photomicrograph of high carbon steel in the annealed condition and reveals a field partly spheroidized and partly lamellar. The spheroids are analogous to the bar of soap or chunks, having a relatively small surface presented to the iron in comparison to its mass. The cementitic lamellae are analogous to the soap flakes, and present a surface infinitely larger for their mass than the spheroids.

Inasmuch as the proper heat treatment of steel is dependent upon a time–temperature relation in which time is equally as important as the temperature, it is readily apparent that a time-temperature equation which will just completely absorb and dis-

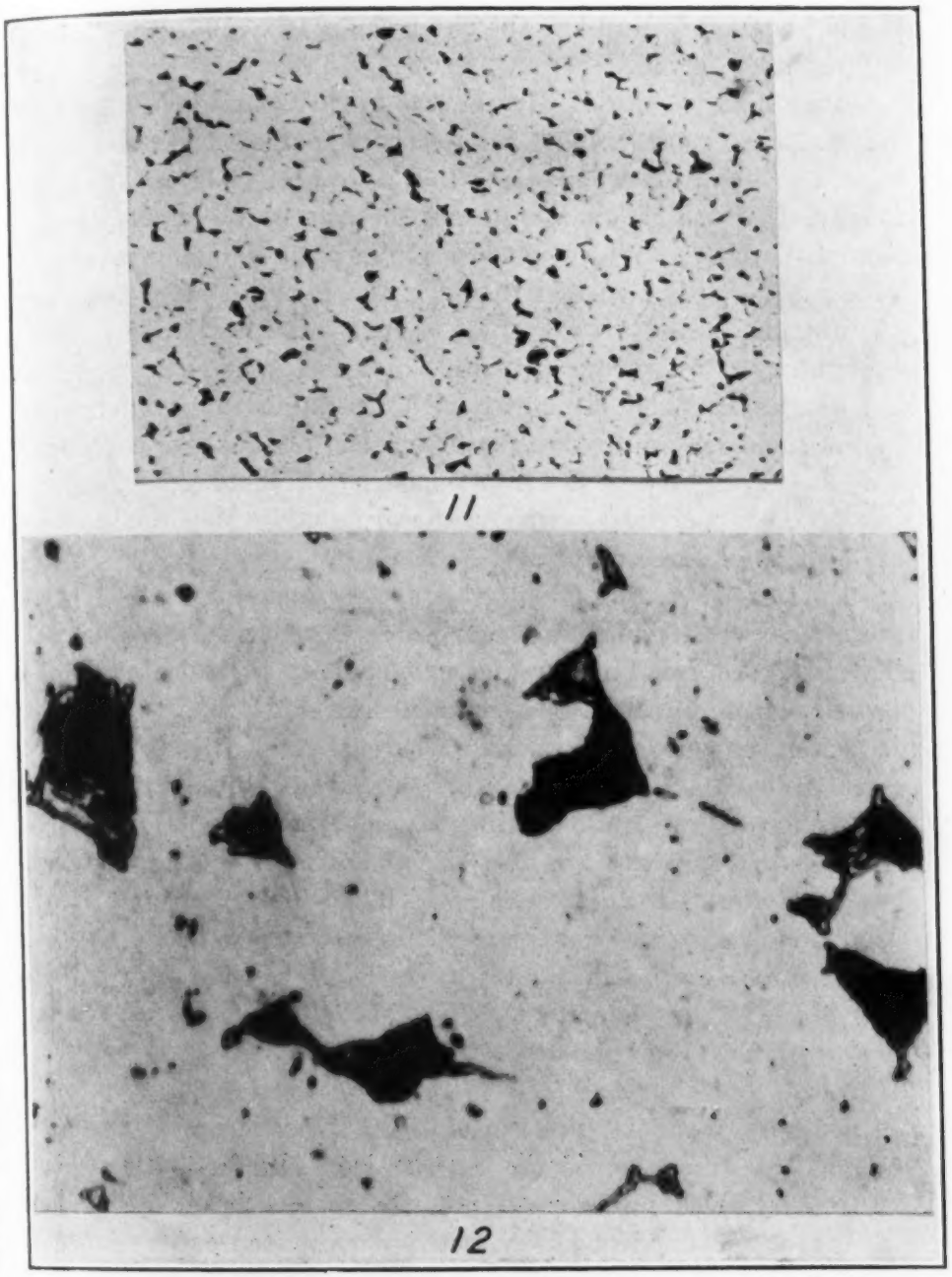


Fig. 11—Photomicrograph of a Specimen of Killed Steel of About 0.09-0.15 Per Cent Carbon. 100x. Fig. 12—Photomicrograph of an Area of Fig. 11 at Higher Magnification. 1500x.

tribute the readily soluble or miscible lamellae in the pearlite, will upon quenching have left some of the spheroidal cementite practically intact and undisturbed. As in the soap solution, the plates

or flakes dissolved and left the chunks, slightly diminished in mass, but yet undissolved.

Photomicrograph of Fig. 14 was made from a specimen shown in Fig. 13 after hardening. An appreciable amount of the spheroids remain as such. It would seem therefore that in high carbon steel at least in which the maximum hardness as well as homogeneity is desired, that the starting structure should be lamellar pearlite.

It is a well-known fact that medium carbon steel is reasonably easy to spheroidize. However, it is next to impossible to reconvert the spheroids to lamellar pearlite which is further evidence of the fact that spheroidal cementite is less soluble than the lamellar. By the same reasoning, two pieces of steel of identical carbon content, one lamellar and the other spheroidal, should have different time lags when critical point graphs are made which would change the location of these points.

Further reasoning along the above lines would lead to the interesting conclusion that carburized iron or steel is capable, when hardened, of a greater degree of homogeneity than ordinary rolled high carbon steel for the reason that in the slowly cooled carburized piece the cementite is lamellar whereas frequently in the high carbon rolled bars the cementite is largely spheroidal. It is well to consider, however, in making comparisons to be sure that the spheroids of cementite are of a size that would be much larger in mass than the average lamellae which has been found to harden satisfactorily with a given time and temperature ratio.

Sometime ago the author to prove the above contention made a wood cutting tool from high carbon stock of about the structure as shown in Fig. 15 and another from carburized ARMCO iron. When hardened the carburized ARMCO iron gave results far in excess of the tool made from the high carbon bar. Upon examination it was revealed that the case of the ARMCO iron had a high degree of homogeneity with no excess cementite present whereas the high carbon tool had hardened very well but exhibited excess cementite globules. True they were very small, nevertheless, they were present. Many of the alloy steels exhibit this characteristic and as is well-known are not suitable for tools having extremely keen edges.

To treat such a subject over such a wide range of carbon content as has been done in this paper may leave some misunderstand-

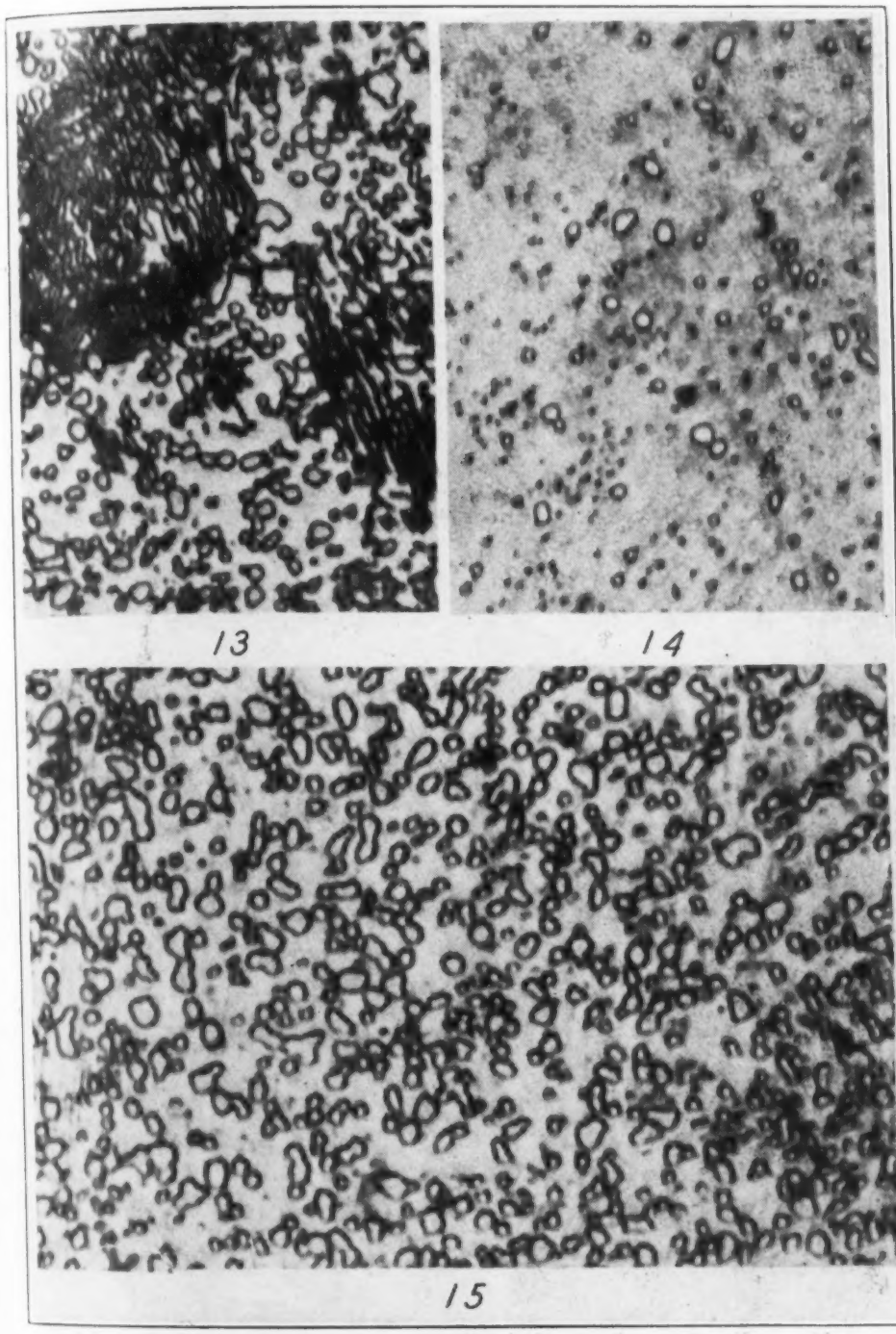


Fig. 13—Photomicrograph of High Carbon Steel in Annealed Condition Showing a Field Partly Spheroidal and Partly Lamellar. 1150x. Fig. 14—Photomicrograph of Specimen Shown in Fig. 13 After Hardening. 1150x. Fig. 15—Photomicrograph of High Carbon Stock used in Making Wood Cutting Tool. 1733x.

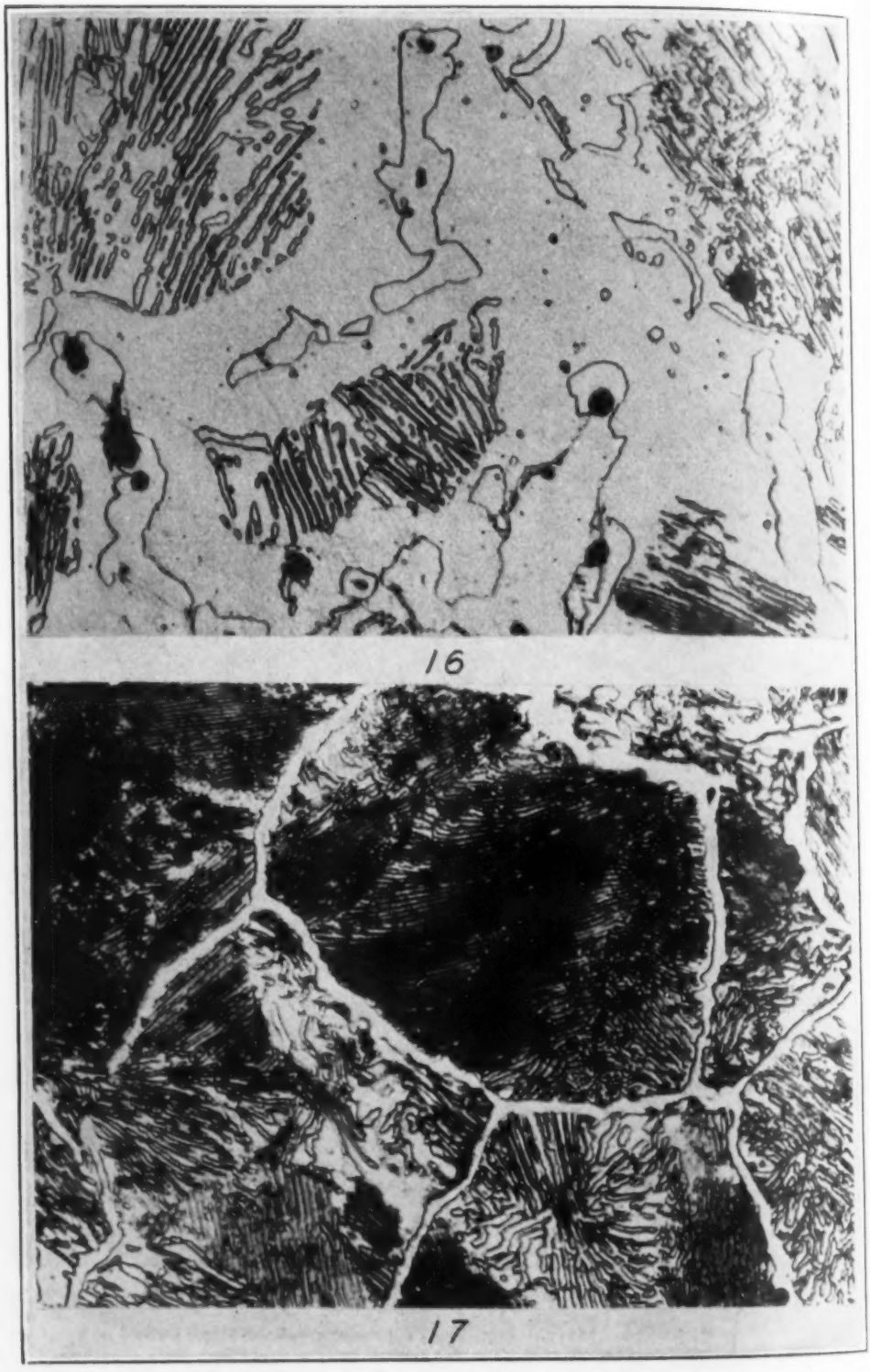


Fig. 16—Photomicrograph of Carburized Abnormal Steel Whose Thermal Behavior is of the Same Class as Structure Shown in Fig. 13. 1000x. Fig. 17—Photomicrograph Showing Presence of Pearlite Together with Regular Configurations of Excess Cementite. 1000x.

ing with the reader, but before proceeding to summarize the foregoing, the subject should not be left without a word about the so-called abnormal steels. Photomicrograph Fig. 16 of carburized abnormal steel shows a situation which as far as thermal behavior is concerned is of the same class as the structure of Fig. 13. Although these two structures are from different causes still the same discussion as far as hardening is concerned that applied to Fig. 13 holds to a marked degree in the case of Fig. 16. The abnormality of this piece is evidenced by the fact that there is present, in addition to the pearlite, two excess constituents. Were this structure normal it would appear as that shown in Fig. 17 in which pearlite is present together with regular configurations of excess cementite.

Returning to the structure shown in Fig. 16 the same explanation of its hardening may be made that was made for the structure shown in Fig. 13 excepting that in Fig. 16 the relation of the surface of the cementite areas compared to their mass is so small that no reasonable relation exists between them and the cementite striations of the pearlite. Were an attempt made to harden this structure of which roughly 50 per cent is pearlite, the resultant product would have large soft areas as any time and temperature just suitable to the pearlite would not affect the cementite-ferrite masses.

Whatever it is that causes cementite to spheroidize in normal steel, when subjected to temperatures just below the critical range, is present to an excess degree in the so-called abnormal steels. Apparently the two phenomena are closely related. There is no doubt but what the abnormality is present in the ferrite only. The author recently examined sections of electrolytic ferrite of a purity of 99.98 per cent iron carburized which in every instance showed extreme abnormality, although some pearlite was present. It is entirely possible that the present use of the term abnormal steel is a misnomer and that the true condition of the pure carbon in pure iron or ferrite is one type of cementite whereas the cementite or lamellar pearlite is of an entirely different composition atomically.

Summary

To summarize the foregoing, it has been shown that the condition of the cementite is very important as follows:

1. In low carbon steels that are not to be subjected to harden-

ing it is desirable to have the cementite in the spheroidal condition for the following reasons:

a—Greater resistance to corrosion
b—Greater ductility
c—Less soluble in acids
d—More stable
e—More readily adaptable to covering by electroplating, enameling, etc.
f—More readily weldable (see a).

2. In high carbon steels to be subjected to hardening it is desirable to have the cementite in the lamellar form for the following reasons:

a—More readily miscible at the hardening temperature for a minimum time
b—Less tendency toward unabsorbed or free cementitic areas
c—Greater homogeneity when hardened
d—Greater average degree of hardness which accrues from a, b, and c.

It is not presumed by the author that this paper embodies anything original or new, but even though the contained points be well-known to the reader it is of vital importance that they be constantly kept in mind when anticipating the behavior of articles manufactured from straight carbon steels. The points touched upon are basic and simple, in fact, so simple, that they are passed over too often by many metallurgists seeking a more complex answer to their problems.

CORROSION-FATIGUE OF METALS AS AFFECTED BY CHEMICAL COMPOSITION, HEAT TREATMENT AND COLD WORKING

By D. J. McAdam Jr.

Abstract

The author briefly gives the results of a previous investigation of corrosion-fatigue of metals and then sets forth the materials, machines and specimens used in further investigation of this subject. The chemical composition of the steels used is tabulated and the stress-cycle graph representing steels tested in air and in a water stream are shown. The writer describes and illustrates the corrosion-fatigue spots and is of the opinion that transverse cracks passing through non-metallic inclusions usually surrounded by oxide coating are the origins of corrosion-fatigue failure. For the investigation, the results of which are given in this paper, corrosion-fatigue tests and ordinary endurance tests were made in a series of carbon steels ranging from 0.033 to 1.09 per cent carbon.

The writer sets forth his findings in experiments with carbon steels, nickel steels, high chromium steels and chromium-nickel steels and gives the effect of chemical composition and physical properties on corrosion-fatigue.

The author is of the opinion that corrosion-fatigue depends on two factors—corrosion intensity and a stress range and that the corrosion-fatigue limit depends on a strength factor as well as on corrosion-resistance.

Part 1.—Corrosion-Fatigue of Steel

Previous Investigation

A preliminary investigation of corrosion-fatigue of metals has been described in a recent paper[1]. In that investigation, rotating-cantilever specimens, of the conically tapered design

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[1]D. J. McAdam, Jr., "Stress-Strain-Cycle Relationship and Corrosion-Fatigue of Metals," presented at Twenty-ninth Annual Meeting of the American Society for Testing Materials and to be published in the proceedings, A. S. T. M., Vol. 26 (1926).

A paper presented before the eighth annual convention of the Society, Chicago, September 20 to 24, 1926. The author, Dr. D. J. McAdam, Jr., is metallurgist U. S. Naval Engineering Experiment Station, Annapolis, Md.

previously described, [2,3,4] were subjected to simultaneous fatigue and corrosion. For this purpose a stream of fresh water was diagonally applied so as to sweep the specimen from the outer to the inner fillet and surround the stressed surface entirely by water. The investigation included carbon and alloy steels heat treated in various ways, ingot iron, and "stainless iron".

The experiments[1] showed that slight corrosion simultaneous with fatigue may cause failure at stresses far below the ordinary endurance limit. It was also shown that severe corrosion prior to fatigue lowers fatigue resistance much less than slight corrosion simultaneous with fatigue. The damaging effect of corrosion was found to be greater the harder the steel. The 'corrosion-fatigue limit' of stainless iron under these conditions was much lower than the "endurance limit," but higher than the corrosion-fatigue limits of the carbon steels and the other alloys steels investigated.

The results given in the previous paper suggested several theories about the relationship of corrosion-fatigue to physical properties and chemical composition. Before discussion of this subject could be more than tentative, however, it was necessary to await the result of further investigation. The investigation has been continued and results are presented in the present paper.

Material

For further investigation of this subject experiments have been made with a series of carbon steels ranging from ingot iron to tool steel, nickel steel, stainless iron, and stainless steel. The stainless irons and steels were obtained from various manufacturers. There were available also additional specimens of the same materials that had been used in a previously described investigation of the endurance properties of corrosion-resistant steels.[4] Other high chromium, high nickel steels were also obtained from various manufacturers.

Machines and Specimens

The rotating-cantilever machines and specimens have been

[2]D. J. McAdam, Jr., "Endurance of Steel Under Repeated Stresses," *Chemical and Metallurgical Engineering*, Dec. 14, 1921.

[3]D. J. McAdam, Jr., "Endurance Properties of Alloys of Nickel and of Copper," Transactions, American Society for Steel Treating, January, 1925.

[4]D. J. McAdam, Jr., "Endurance Properties of Corrosion-Resistant Steels," *Proceedings*, A. S. T. M., Vol. 24, Part 2, 1924.

described in previous papers.[2,3,5] The conically tapered specimen is so designed that the maximum stress is ¾ inch out from the inner fillet, and the stress varies only about 1½ per cent over a length of 1½ inches. With this specimen, therefore, a comparatively large region may be subjected to corrosion-fatigue.

The method of alternate longitudinal and transverse polishing of this specimen has been previously described.[5] For the specimens used in this investigation, however, a smoother polish was used than for specimens used in the previous investigations. The surface finish was sufficiently smooth to permit examination of the microstructure at 100 magnification. Details of machining and polishing are tabulated and kept on file at the Naval Experiment Station. This information is available for those who are interested.

Chemical Composition

The chemical composition of the steels used is given in Table I. Trade names, except those that are in universal use, have been avoided, and each material has been designated by a combination of letters.

Heat Treatment

Details of heat treatment are given in Table II. In Table III are listed a number of corrosion-resistant steels that were used in a previous investigation on "Endurance Properties of Corrosion-Resistant Steels."[4] Steels remaining after that investigation have been used in this investigation of corrosion-fatigue. As a new system of designations has recently been adopted, both new and old designations for the same material are given in Table III.

Tension Tests

Results of Tension Tests are given in Table IV.

The Stress-Cycle Graph; Effect of Water Stream

Stress-cycle graphs representing steels tested in air and in a water stream are shown in Figs. 1 to 4. The tests are of three kinds: 'endurance' tests, in which the specimen is tested without water stream; 'corrosion-fatigue' tests, in which the specimen is tested in a water stream to failure; and 'interrupted corrosion' tests,

[5] D. J. McAdam, Jr., "Endurance Properties of Steel: Their Relation to Other Physical Properties and to Chemical Composition," *Proceedings*, A. S. T. M., Vol. 23, Part 2, 1923.

in which the water stream is removed from the specimen before failure.

The fresh water used is a well water having the following composition when tested after a dry period of about 20 days duration:

Composition expressed in grains per U. S. gallon	
Silica	0.68
Iron and aluminum oxides	None
Calcium sulphate	0.11
Calcium carbonate	11.66
Magnesium chloride	1.02
Sodium chloride	8.30
Sodium sulphate	...
Total solids	21.77

Results of 'endurance' tests are shown in the graphs marked "A." It has been shown in previous papers [1,6] that the lower part of the stress-cycle line is a curve with a horizontal asymptote, and

Table I
Chemical Composition of Material
All values in per cent.

Material	Material Designation	C	Mn	P	S	Si	Ni	Cr	Cu
Stainless Iron	GO	0.08	0.18	0.015	0.013	0.23	0.18	12.20	0.13
Stainless Iron	FH	0.11	0.04	0.014	0.017	0.10	0.07	11.84	0.94
Stainless Steel	FJ	0.33	0.08	0.016	0.025	0.09	0.08	11.54	0.84
Stainless Iron	GN	0.13	0.05	0.040	0.033	0.22	0.08	13.35	0.45
Stainless Iron	FI	0.09	0.07	0.018	0.023	0.10	0.12	13.76	0.16
Stainless Iron	GD	0.09	0.29	0.011	0.022	0.10	0.15	15.09	0.01
High-Chromium Steel	GA	0.24	0.51	0.010	0.020	0.27	0.25	20.48	0.67
Chromium-Nickel Steel	FL	0.16	0.28	0.006	0.013	0.44	8.19	17.32	0.08
Chromium-Nickel Steel	EX	0.80	0.86	0.017	0.045	1.70	12.19	19.01	0.05
Chromium-Nickel Steel	EW	0.38	0.71	0.020	0.048	2.36	15.88	15.95	0.08
Chromium-Nickel Steel	EV	0.39	0.66	0.018	0.030	0.144	25.27	17.71	0.012
Chromium-Nickel Steel	EU	0.70	0.72	0.018	0.060	3.08	25.81	17.32	0.05
Chromium-Nickel Steel	ES	0.24	0.80	0.010	0.027	1.65	22.90	5.42	0.78
Chromium-Nickel Steel	FZ	0.24	0.39	0.015	0.020	0.56	22.14	6.04	0.82
Chromium-Nickel Steel	ET	0.45	0.49	0.012	0.022	1.39	28.20	8.38	0.67
Chromium-Nickel Steel	FK	0.39	1.10	0.002	0.011	0.15	34.70	10.89	None
Ingot Iron	EK	0.033	0.025	0.005	0.036	0.003	....	....	...
0.11% Carbon Steel	B	0.112	0.39	0.008	0.038	0.005	....	....	...
0.14% Carbon Steel	G	0.137	0.47	0.009	0.037	0.057	....	....	...
0.24% Carbon Steel	EL	0.24	0.40	0.009	0.028	0.023	....	....	...
0.26% Carbon Steel	EN	0.26	0.57	0.009	0.036	0.06	....	....	...
0.36% Carbon Steel	AG	0.362	0.61	0.009	0.015	0.019	....	....	...
0.49% Carbon Steel	AE	0.49	0.41	0.010	0.006	0.23	....	....	...
High Carbon Steel	EM	1.09	0.33	0.023	0.015	0.28	....	....	...
3½% Nickel Steel	EJ	0.32	0.60	0.028	0.023	0.21	3.47	....	...
5% Nickel Steel	CA	0.52	0.41	0.022	0.009	0.32	5.37	....	...

that the ordinate of the asymptote is the endurance limit. It has also been shown that when extended upward the stress-cycle 'endur-

[6]D. J. McAdam, Jr., "Endurance Properties of Non-Ferrous Metals, Part 11, Paper 1537 D, American Institute of Mining and Metallurgical Engineers, issued with *Mining and Metallurgy*, February, 1926.

ance' line often reverses its curvature. This is due to rise in temperature during the endurance test. The heat evolved may even cause highly stressed specimens to become bright red hot. These characteristics of the ordinary stress-cycle graph for steel are well illustrated in Figs. 1 to 4.

Table II
Heat Treatment

Material	Material Designation	Heated to Deg., Fahr.	Time Held, Minutes	Cooled in	Reheated to Deg., Fahr.	Time Held, Minutes	Cooled in	Reheated to Deg., Fahr.	Time Held, Minutes	Cooled in
Ingot Iron	EK-17.5	1750	30	Furnace	....	...	....	....	..	....
Ingot Iron	EK-W-7	1750	45	Water	700	120	Furnace	....	..	....
0.11% Carbon Steel..	B-17.25	1725	30	Furnace	....	...	....	....	..	....
0.14% Carbon Steel..	G-W	1725	30	Water	....	...	....	....	..	....
0.24% Carbon Steel..	EL-16.5	1650	60	Furnace	....	...	....	....	..	....
0.26% Carbon Steel..	EN-W-9	1650	60	Water	900	120	Furnace	....	..	....
0.36% Carbon Steel..	AG-15.5	1550	60	Furnace	....	...	....	....	..	....
0.36% Carbon Steel..	AG-W-9	1550	60	Water	900	120	Furnace	....	..	....
0.49% Carbon Steel..	AE-15	1500	60	Furnace	....	...	....	....	..	....
0.49% Carbon Steel..	AE-W-10	1500	60	Water	1000	120	Furnace	....	..	....
High Carbon Steel....	EM-14.75	1475	60	Furnace	....	...	....	....	..	....
3½% Nickel Steel...	EJ-14.5	1675	30	Air	1450	60	Furnace	....	..	....
3½% Nickel Steel...	EJ-W-10	1675	30	Air	1450	60	Water	1000	120	Furnace
5% Nickel Steel.....	CA-14.25	1425	60	Furnace	....	...	....	....	..	....
5% Nickel Steel.....	CA-W-11	1425	60	Water	1100	120	Furnace	....	..	....
Stainless Iron	GO-18	1800	120	Furnace	....	...	....	....	..	....
Stainless Iron	GO-W-12	1800	60	Water	1200	120	Air	....	..	....
Stainless Iron	FH-16	1600	120	Furnace	....	...	....	....	..	....
Stainless Steel	FJ-17	1700	120	Furnace	....	...	....	....	..	....
Stainless Iron	GN-W-12	1800	90	Water	1200	120	Air	....	..	....
Stainless Iron	FI-W-12	1800	90	Water	1200	120	Air	....	..	....
Chromium-Nickel Steel	EW-17	1700	30	Furnace	....	...	....	....	..	....
Chromium-Nickel Steel	ET-17	1700	30	Furnace	....	...	....	....	..	....

ADDENDA TABLE II

Material	Designation
Stainless Iron	GD*
High Chromium Steel	GA*
Chromium-Nickel Steel	FL*
Chromium-Nickel Steel	FLA*
Chromium-Nickel Steel	FZ†
Chromium-Nickel Steel	FK*

*Heat treatment unknown.
†Normalized at 1300 degrees Fahr. by manufacturer.

The effect of water cooling highly stressed specimens is also shown in these figures. By water cooling it is possible to extend the stress-cycle line above the nominal tensile strength of the material. When steel specimens are tested at stresses that cause failure in less

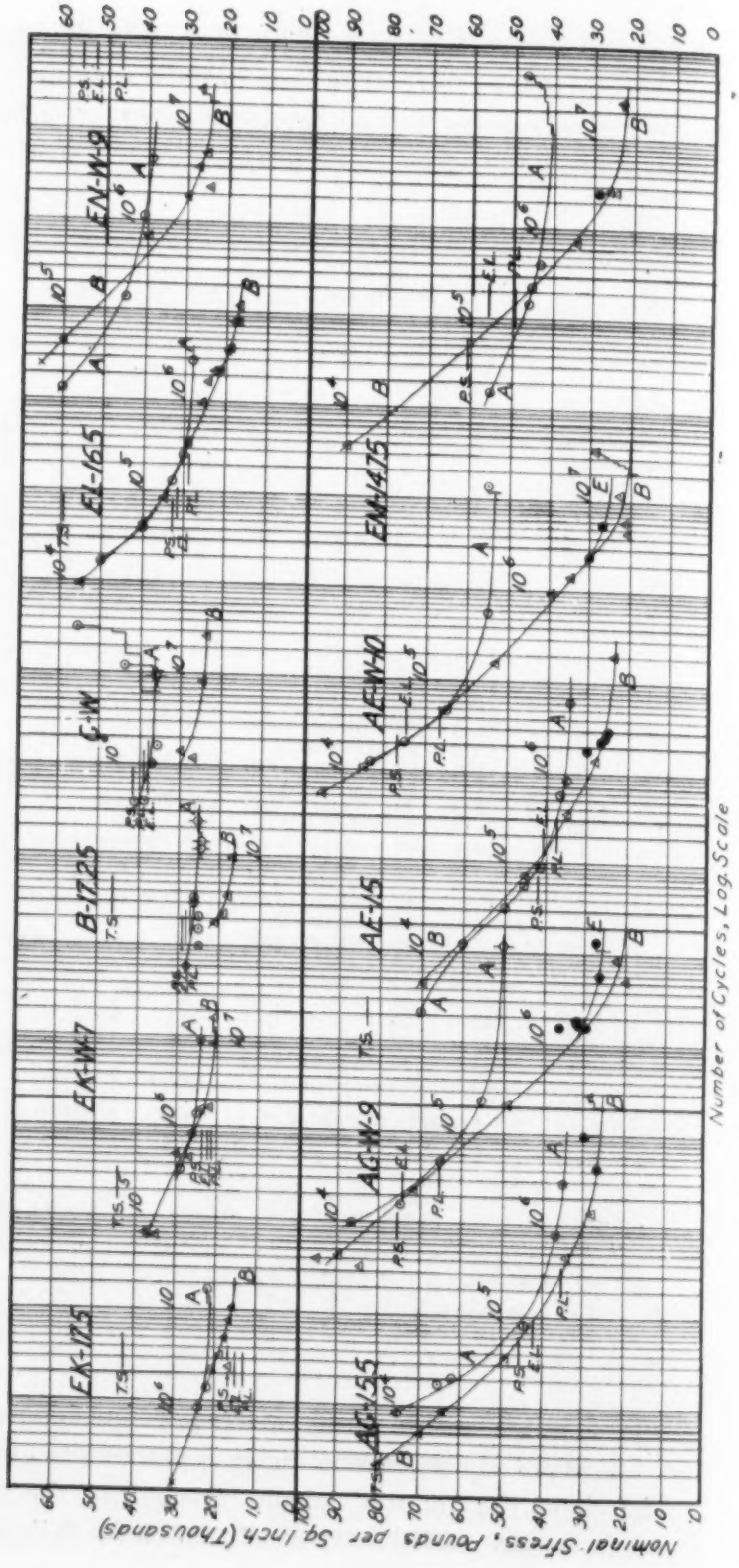


Fig. 1—Corrosion-Fatigue of Carbon Steels. (See Legend, Page 363)

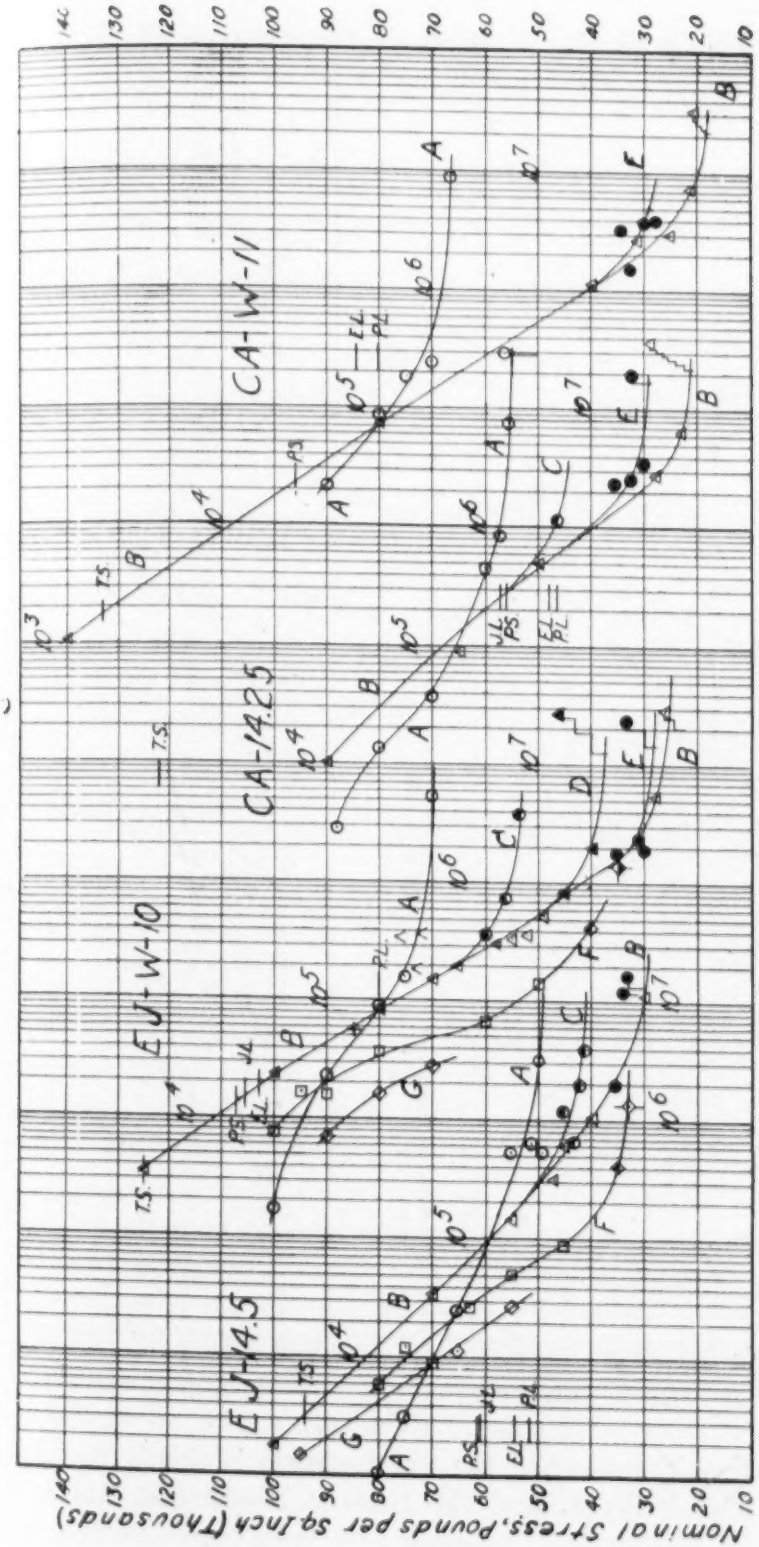


Fig. 2—Corrosion-Fatigue of 3½ and 5% Nickel Steels. *(See Legend, Page 363)*

Fig. 1—Corrosion-Fatigue of Carbon Steels. *(See Legend, Page 363)*

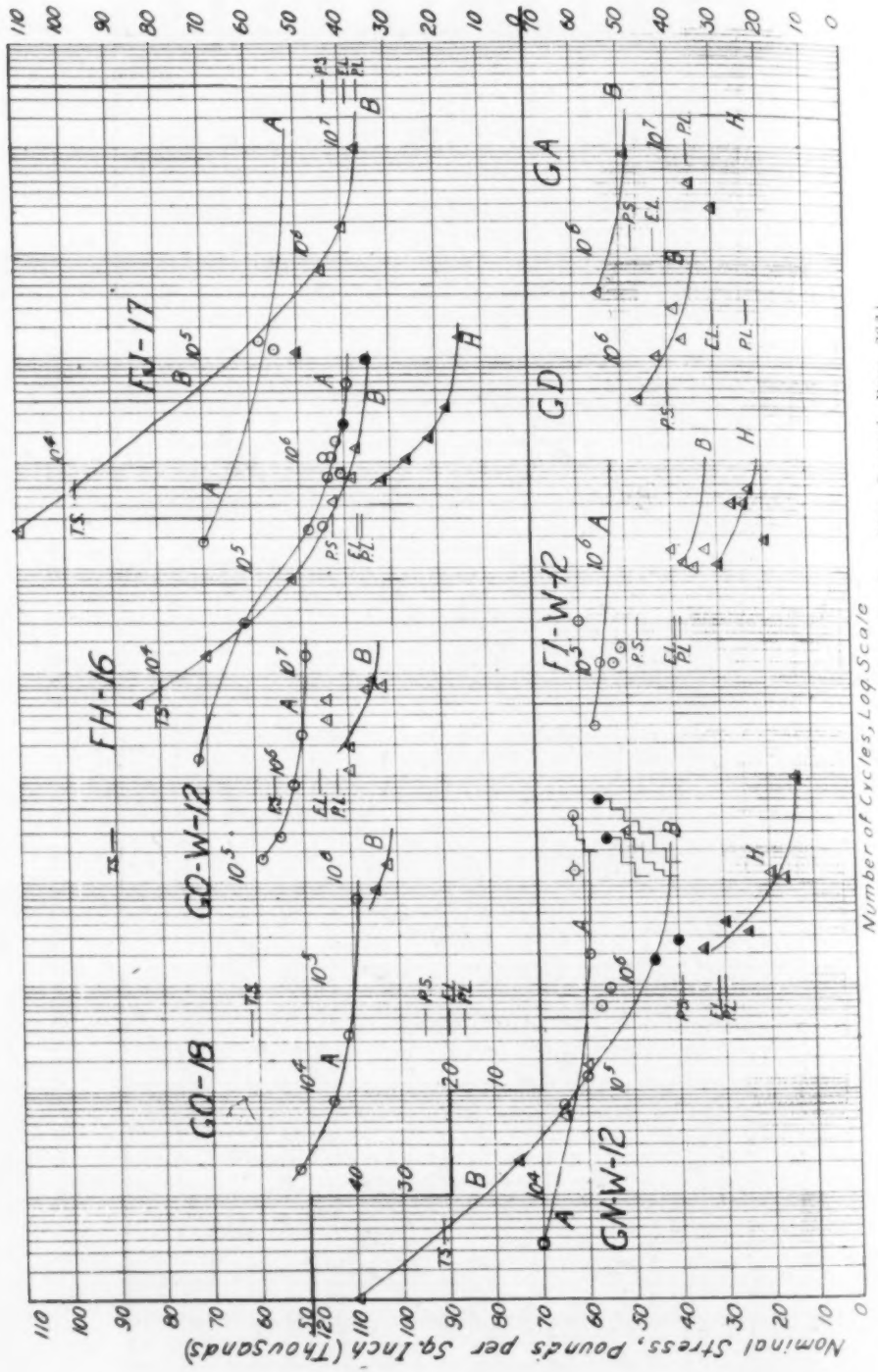


Fig. 3—Corrosion Fatigue of High-Chromium Steels. (See Legend, Page 363)

than an hour the effect of the water stream is chiefly thermal. As the stress is lowered, and the time is lengthened, however, the thermal effect becomes negligible and the chemical effect becomes

LEGEND FOR FIGS. 1 to 4

T.S.	.....Tensile strength
J.L.	.....Johnson's limit
P.S.	.....Proof stress
E.L.	.....Elastic limit
P.L.	.....Proportional limit
A--⊙	.....1450 r.p.m., in air
◒	.....1450 r.p.m., in air. Taken from previous paper on "Endurance Properties of Corrosion Resistant Steels."
∧	..... 50 r.p.m., in air
+	..... 4 r.p.m., in air
B--△	.....1450 r.p.m., in fresh water to failure.
×	.....1200 r.p.m., in fresh water to failure.
F--⊡	..... 50 r.p.m., in fresh water to failure.
◆	..... 50 r.p.m., in fresh water first 55,000 cycles
◆	..... 50 r.p.m., in fresh water first 150,000 cycles
G--◈	..... 5 r.p.m., in fresh water to failure.
C--◓	.....1450 r.p.m., in fresh water first 100,000 cycles
D--▲	.....1450 r.p.m., in fresh water first 300,000 cycles
E--●	.....1450 r.p.m., in fresh water first 1,500,000 cycles
◔	.....1450 r.p.m., for periods of about 3,000,000 cycles alternately in water and air.
H--▲	.....1450 r.p.m., in salt water to failure.
−|−	.....Removed at this stress.

prominent. With decreasing stress, as shown in Figs. 1 to 4, graph "B" for specimens tested in fresh water descends below graph "A." This 'corrosion-fatigue' graph resembles the endurance graph in that it apparently approaches a horizontal asymptote. The ordinate of this asymptote may be called a 'corrosion-fatigue' limit.

For some carbon or nickel steels, as shown in Figs. 1 and 2, the corrosion-fatigue limit may be less than one third the endurance limit. Graph "B" at about 100,000 cycles begins to descend rapidly below graph "A", and the steepest descent is between 100,000 and 400,000 cycles; this corresponds to only 1¼ to 5 hours at 1450 r. p. m. Specimens that failed after this time in a water stream had not become heavily rusted, but appeared fairly bright. Closer examination, however, showed numerous small spots of dull ap-

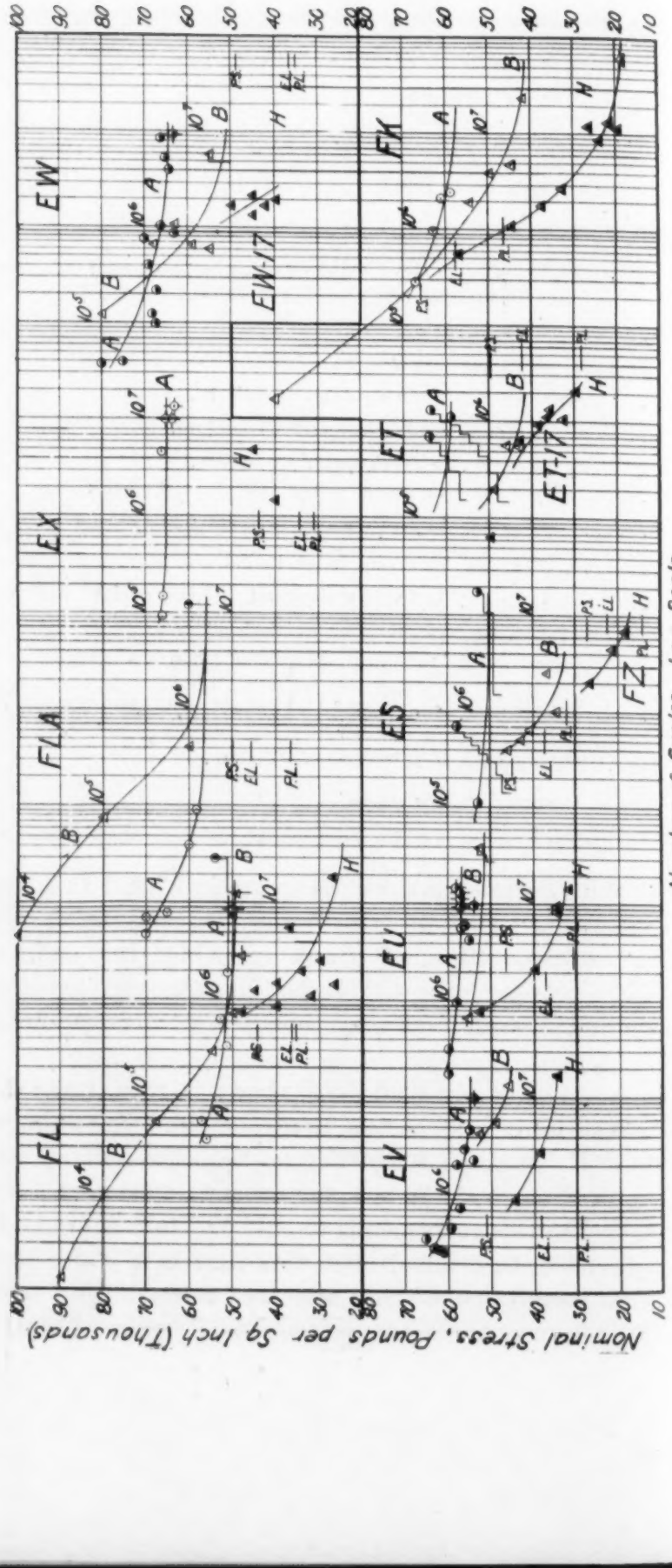


Fig. 4—Corrosion-Fatigue of Chromium-Nickel Steels. *(See Legend, Page 363)*

pearance. After 100,000 cycles in water these spots were hardly visible without a hand lens. The appearance of the spots at higher magnification is shown in the photomicrographs, Figs. 7 to 12 inclusive, which will be discussed later.

'Interrupted corrosion' tests, as illustrated in Figs. 1 and 2, show that the amount of corrosion need be very slight to lower greatly the fatigue resistance of the steel. As shown in Fig. 2, the corrosion-fatigue limit for specimens in water stream for only 100,000 cycles (1¼ hours) is about midway between the endurance limit and the corrosion-fatigue limit for 1,500,000 cycles (18 hours) in water stream.

Character of Corrosion-Fatigue Spots

The corrosion-fatigue spots described above are illustrated by Figs. 7 to 12 inclusive. These spots at magnification of 100 show transverse cracks passing through non-metallic inclusions usually surrounded by oxide coating. Such cracks are origins of corrosion-fatigue failure. They are numerous in most specimens of failed carbon and alloy steels. In stainless iron only a few such spots are visible in specimens tested considerably above the corrosion-fatigue limit; none are visible in specimens tested only slightly above corrosion-fatigue limit.

Corrosion-Fatigue of Carbon Steels

For this investigation corrosion-fatigue tests and ordinary endurance tests were made on a series of carbon steels ranging from 0.033 to 1.09 per cent carbon. With the exception of the high carbon steel, each of the steels was heat treated in two different ways. Results of corrosion-fatigue tests of these steels are given in Fig. 1, in which each material is designated by a combination of letters and numbers. The chemical composition, heat treatment, and physical properties may be found by reference to the corresponding designations in Table I, II, and IV.

The graphs in Fig. 1 are arranged on semi-logarithmic scale in order of increasing carbon content. Each graph has its own abscissa scale, which is indicated by numbers along the graph. On each graph are indicated, by short horizontal lines with proper ordinates, either the tensile proof stress or Johnson's limit, elastic

Number of Cycles, Log Scale.

Fig. 4—Corrosion-Fatigue of Chromium-Nickel Steels. (See Legend, Page 363)

limit, and proportional limit. When the ordinate scale permits, the tensile strength is similarly indicated.

The six graphs in the upper row of Fig. 1 represent steel of three different carbon percentages, each heat treated in two different ways. The first four graphs in the lower row represent steel of two different carbon percentages, each heat treated in two different ways. The last graph in the lower row represents annealed high carbon steel.

A comparison of the first two graphs of the upper row shows that the 'quench and draw' treatment of ingot iron has increased both endurance limit and corrosion-fatigue limit above those of fully annealed ingot iron. The proportional increase in the corrosion-fatigue limit is at least as great as the proportional increase in the endurance limit. A comparison of the next two graphs representing rivet steel, shows that the quenching treatment has increased the endurance limit and corrosion-fatigue limit by about the same proportion above that of fully annealed rivet steel. A comparison of the last two graphs of the upper row shows a similar relationship for 0.24 per cent carbon steel. It should be noted that the pair of graphs for ingot iron represent material from the same heat. This is not true of the pairs representing rivet steel and 0.24 per cent carbon steel.

A comparison of the first two pairs of graphs in the lower row of Fig. 1 shows that the 'quench and draw' treatment has lowered the corrosion-fatigue limit of 0.36 per cent and 0.49 per cent carbon steel slightly below the corrosion-fatigue limit of fully annealed material.

With the exception of the annealed low-carbon steels the corrosion-fatigue limit for all the steels represented in Fig. 1 is between 20,000 and 25,000 pounds per square inches. For annealed low carbon steels the corrosion-fatigue limit is between 15,000 and 17,000. If therefore, the graphs in Fig. 1 are representative of carbon steels, they seem to indicate that for all sorbitic steels, and for pearlitic steels having between about 0.3 and 1.1 per cent carbon, the corrosion-fatigue limit is practically the same. For low-carbon pearlitic steels, the corrosion-fatigue limit is somewhat lower.

Sorbitizing heat treatment, therefore, does not improve the corrosion-fatigue limit of any except low carbon steels. The range

of carbon content in which sorbitizing heat treatment is of most benefit to the endurance limit is the range in which it is of practically no benefit to the corrosion-fatigue limit. Corrosion-fatigue of troostitic and martensitic steels has not been investigated.

Corrosion-Fatigue of Nickel Steels

Results of investigation of corrosion-fatigue of nickel steels are given in Fig. 2. In this figure there are four groups of graphs. In each of these four groups, graphs "A", "B" and "E" have the same significance as in Fig. 1. In Fig. 2, however, there are also graphs "C" and "D" giving additional results of 'interrupted corrosion' tests, and graphs "F" and "G" giving results of corrosion-fatigue tests at lower cycle frequencies.

As shown by graphs "A" and "B", sorbitizing heat treatment while greatly improving the endurance limit, has lowered the corrosion-fatigue limit of the sorbitic steels below that of fully annealed material. The corrosion-fatigue limit of the 3½ per cent nickel steels is somewhat higher than that of carbon steels. The corrosion-fatigue limit of the 5 per cent nickel steels, however, is no higher than that of carbon steels. This is probably due to the fact that the 5 per cent nickel steel, as shown by the large number of non-metallic inclusions and low ductility, is not of the best quality. It seems probable that good steels having this nickel content are slightly more resistant to corrosion than carbon steels. It might be expected, therefore, that such nickel steels would have a slightly higher corrosion-fatigue limit than carbon steels. Whether the relatively low corrosion-fatigue limit of the 5 per cent nickel steel is due to lowered corrosion resistance due to inferior quality, or to the lowered ductility, cannot be decided at this time.

Graphs "F" and "G" represent corrosion-fatigue tests at 50 and 5.6 revolutions per minute respectively. As shown by graphs "B", "F" and "G," with decrease in cycle frequency the corrosion-fatigue graph is moved to the left. At low cycle frequency specimens fail at much fewer cycles than at high cycle frequency. This is evidently due to the increase in corrosion time per cycle with decrease in cycle frequency. Moreover, although with decrease in cycle frequency the number of cycles to failure decreases, the total time to failure increases.

Relationship between corrosion time and the total number of

cycles to failure is illustrated in Figs. 5 and 6. In these figures the solid-line curves illustrate relationship between corrosion time and number of cycles for constant stress and varying cycle frequency. The broken-line curves illustrate relationship, on the semi-logarithmic scale, between corrosion time and number of cycles for constant cycle frequency; on Cartesian coordinate scale this relationship would be represented by straight lines.

The solid lines in Figs. 5 and 6, illustrate the fact that the number of cycles to failure decreases with increase in corrosion time. The curvature of these lines shows that with increase in total time the effect of corrosion time grows less. Curves representing stresses above the endurance limit necessarily intersect the axis of ordinates. Curves representing stresses below the endurance limit do not intersect this axis. As the stress decreases toward the corrosion-fatigue limit the effect of decrease in stress on the position of the time-cycle curve becomes greater. This is illustrated in Figs. 5 and 6 by the positions of the curves representing stresses of 30,000 and 28,000 respectively. Evidently these stresses are near the respective corrosion-fatigue limits.

As shown in Fig. 2, the corrosion-fatigue limit for low cycle frequency is evidently no lower, and may be slightly higher, than the corrosion-fatigue limit for high cycle frequency. The higher ratio of corrosion time to number of cycles may give greater opportunity for formation of a protective coating and thus raise the corrosion-fatigue limit. That thick coatings may afford such protection is also indicated by the fact that specimens, tested for some time slightly below the corrosion-fatigue limit, will then endure considerable increases of stress before failure. This is shown in Figs. 1 to 4 by the zig-zag lines each representing the courses of a corrosion-fatigue test.

The relationship, illustrated in Fig. 2, between corrosion-time and cycles to failure is of practical importance because it explains mysterious failures at stresses below the endurance limit and after few cycles. For example the 3½% nickel steels illustrated in Fig. 2, stressed just below the endurance limit, with a cycle frequency of 5.6, would fail at only 30,000 or 40,000 cycles. With lower cycle frequency, the number of cycles necessary to cause failure would be still less.

Corrosion-Fatigue of High-Chromium Steels

Corrosion-fatigue of high chromium steels is illustrated by the graphs in Fig. 3. With one exception each steel represented in Fig. 3 is either a "stainless iron" or a "stainless steel." One steel represented in this figure has a chromium content above the range of stainless iron or stainless steel. The graphs are arranged approximately in order of increasing chromium content. The chemical composition, heat treatment, and physical properties of each material are given in Tables I, II and III.

Table III
Heat Treatment

Material	New Material Designation	Old* Material Designation	Condition
Chromium-Nickel Steel	EX	H-r	Annealed by Manufacturer
Chromium-Nickel Steel	EW	G-r	Annealed by Manufacturer
Chromium-Nickel Steel	EV	F-r	Annealed by Manufacturer
Chromium-Nickel Steel	EU	E-r	Annealed by Manufacturer
Chromium-Nickel Steel	ES	C-r	Annealed by Manufacturer
Chromium-Nickel Steel	ET	D-r	Annealed by Manufacturer

*Used in a Previous Paper on "Endurance Properties of Corrosion-Resistant Steels."

Corrosion-fatigue experiments were made with fresh water, and with salt water. The composition of the fesh water has been given. The salt water used is Severn River water, having a saline content about one-third that of sea water.

Graphs "A" and "B" respectively, represent results of endurance tests and of fresh water corrosion-fatigue tests. A comparison of Graphs "B" in Fig. 3 with Graphs "B" in Figs. 1 and 2 shows that the fresh water corrosion-fatigue limit Sc for high chromium steels is much higher than for carbon and nickel steels. For the stainless irons and stainless steel having 11.54 to 15.09 per cent chromium the corrosion-fatigue limit Sc evidently varies irregularly between 30,000 and 40,000 pounds per square inches. For all but one of these, Sc is between 30,000 and 35,000. It seems to make little difference whether these steels are annealed or quenched and drawn at 1200 degrees Fahr. For material GA, having over 20 per cent chromium, the corrosion-fatigue limit is distinctly higher, about 47,000 pounds per square inch. The corrosion-fatigue limit for these high chromium steels evidently depends chiefly on corrosion-resistance, and this depends chiefly on the amount of chromium in solid solution. Variation in carbon

Table IV

Static Tension Test Results
Averages and Mean Departure from Averages

Material	Material Designation	Condition	Tensile Strength, Lbs. Per Sq. In.	Johnson's Limit, Lbs. Per Sq. In.	Proof Stress, Lbs. Per Sq. In.	Elastic Limit, Lbs. Per Sq. In.	Proportional Limit, Lbs. Per Sq. In.	Elongation in 2 In., Per Cent	Reduction of Area, Per Cent
Stainless Iron	GO-18	Annealed	61,500 ±000	23,500 ±1,500	24,500 ±500	19,500 ±500	16,000 ±1,000	41.0 ±1.0	67.5 ±2.0
Stainless Iron	GO-W-12	Quenched and Drawn	90,300 ±1,800	57,500 ±2,500	56,000 ±4,000	46,500 ±3,500	42,500 ±2,500	26.5 ±2.5	74.8 ±3.3
Stainless Iron	FH-16	Annealed	79,800 ±600d	41,000 ±0,000d	42,300 ±800d	36,800 ±1,800d	36,000 ±1,000d	31.9 ±0.9d	65.6 ±1.6d
Stainless Steel	FJ-17	Annealed	97,600 ±800c	43,300 ±1,100c	43,000 ±1,300c	38,700 ±900c	36,000 ±1,300c	27.7 ±0.2c	59.5 ±2.0c
Stainless Iron	GN-W-12	Quenched and Drawn	91,200 ±2,400e	41,400 ±3,900e	39,400 ±5,700e	31,800 ±3,600e	30,000 ±2,000e	25.3 ±1.4e	63.5 ±2.6e
Stainless Iron	FI-W-12	Quenched and Drawn	84,900 ±200c	47,500 ±1,600c	47,300 ±1,900	39,300 ±2,900c	38,300 ±2,200c	28.3 ±0.6c	70.8 ±0.7c
Stainless Iron.....	GD	As Received	102,700 ±6,400	40,000 ±000	40,000 ±000	30,000 ±000	22,500 ±2,500	25.7 ±0.8	59.0 ±9.0
High-Chromium Steel ..	GA	As Received	110,900 ±1,700	49,000 ±14,000	47,000 ±17,000	42,500 ±12,500	35,000 ±5,000	22.5 ±4.0	41.5 ±7.5
Chromium-Nickel Steel..	FL	As Received	125,300 ±2,100d	44,000 ±1,000d	44,200 ±2,300d	36,200 ±1,900d	35,200 ±2,100d	45.5 ±1.5d	53.2 ±1.5d
Chromium-Nickel Steel..	FLA	As Received	133,000 ±3,500d	47,500 ±2,500	50,000 ±1,500d	45,300 ±2,400d	36,500 ±1,500	46.8 ±0.8	56.3 ±0.3
Chromium-Nickel Steel..	EX	As Received	126,500 ±4,000c	45,700 ±2,600c	43,800 ±1,300	34,000 ±1,000	30,700 ±900c	22.0 ±0.7c	25.7 1.8c
Chromium-Nickel Steel..	EW	As Received	128,000 ±1,300c	55,000 ±1,300c	52,000 ±2,000c	36,500 ±1,000c	33,300 ±2,200c	24.8 ±0.2c	37.8 ±0.2c
Chromium-Nickel Steel..	EW-17	Annealed	126,300 ±1,300	51,500 ±1,500	45,000 ±000	35,000 ±000	35,000 ±000	26.0 ±0.0	38.0 ±0.0
Chromium-Nickel Steel..	EV	As Received	115,200 ±2,400d	53,100 ±1,600d	51,000 ±1,300c	38,300 ±2,200c	28,800 ±1,900d	22.5 ±0.5d	34.9 ±1.4d
Chromium-Nickel Steel..	EU	As Received	108,600 ±1,100d	46,900 ±1,400d	46,500 ±1,000c	37,200 ±200c	30,500 ±5,200d	20.0 ±4.2d	26.8 ±7.0d
Chromium-Nickel Steel..	ES	As Received	98,000 ±1,400c	43,700 ±1,100	44,500 ±300	37,000 ±1,300	31,700 ±4,400	32.3 ±0.9	58.6 ±1.06
Chromium-Nickel Steel..	FZ	As Received	85,200 ±200	27,500 ±2,500	27,000 ±2,000	22,500 ±2,500	13,500 ±1,500	43.0 ±1.0	50.0 ±5.0

Unless Otherwise Indicated, Each Value is Average of Two Determinations.
a—One Determination Only.
c—Average of Three Determinations.
d—Average of Four Determinations.
e—Average of Five Determinations.

Table IV—Continued

Static Tension Test Results
Averages and Mean Departure from Averages

Material	Material Designation	Condition	Tensile Strength, Lbs. Per Sq. In.	Johnson's Limit, Lbs. Per Sq. In.	Proof Stress, Lbs. Per Sq. In.	Elastic Limit, Lbs. Per Sq. In.	Proportional Limit, Lbs. Per Sq. In.	Elongation in 2 In., Per Cent	Reduction of Area, Per Cent
Chromium-Nickel Steel..	ET	As Received	111,100	52,500	.....	.....	22,800	24.0	48.9
			.....	.....	.....	.....	.....	...	...
Chromium-Nickel Steel..	ET-17	Annealed	113,300	46,000	49,000	45,000	32,300	24.7	35.5
			±300	±000	±000	±000	±2,200	±1.3	±2.0
Chromium-Nickel Steel..	FK	As Received	112,300	67,200	65,600	57,600	46,600	28.8	46.6
			±4,000c	±1,400c	±3,900c	±5,100c	±2,200c	±1.4c	±1.4c
Ingot Iron	EK-W-7	Quenched and Drawn	43,900	23,000	22,800	21,500	21,000	45.5	75.0
			±100	±1,000	±300	±500	±1,000	±0.5	±0.0
Ingot Iron	EK-17.5	Annealed	42,300	15,500	16,300	15,000	13,000	47.0	72.5
			±300	±500	±300	±1,000	±1,000	±0.5	±1.0
0.11% Carbon Steel....	B-17.25	Annealed	46,400g	27,100g	28,500	28,000	27,000g	47.5g	72.0g
			±300	±1,200	±000	±000	±1,100	±0.9	±0.26
0.14% Carbon Steel....	G-W	Quenched	70,100d	43,400d	41,000	39,000	39,000d	30.5d	73.1d
			±900	±2,600	±000	±000	±2,000	±2.3	±1.9
0.24% Carbon Steel....	EL-16.5	Annealed	59,200c	31,700c	32,500c	31,300c	28,700c	37.8c	59.0c
			±100	±400	±300	±900	±2,400	±0.4	±0.7
0.26% Carbon Steel....	EN-W-9	Quenched and Drawn	84,500c	56,300c	56,300c	52,800c	47,000c	28.2c	64.7c
			±2,300	±2,400	±2,400	±3,200	±2,000	±2.1	±1.4
0.36% Carbon Steel....	AG-15.5	Annealed	79,200e	45,200e	45,400e	41,800e	35,000e	31.3e	48.7e
			±1,100	±2,200	±2,100	±7,300	±2,800	±0.8	±0.5
0.36% Carbon Steel....	AG-W-9	Quenched and Drawn	103,600c	75,700c	75,300c	74,700c	65,000c	25.0c	57.8c
			±1,600	±2,200	±2,900	±3,100	±5,300	±1.3	±2.0
0.49% Carbon Steel....	AE-15	Annealed	82,900c	43,000c	41,700c	40,300c	37,000c	27.8c	43.7c
			±1,100	±2,000	±900	±400	±2,700	±1.1	0.4
0.49% Carbon Steel....	AE-W-10	Quenched and Drawn	110,900c	75,700c	76,800c	74,200c	65,800c	24.0c	54.3c
			±2,500	±2,400	±1,900	±4,400	±1,900	±0.3	±1.9
High-Carbon Steel	EM-14.75	Annealed	103,400d	60,300d	60,600d	55,800d	49,500d	29.5d	50.8d
			±4,100	±2,800	±2,900	±3,700	±2,300	±1.3	±2.4
3½% Nickel Steel.....	EJ-14.5	Annealed	92,500d	61,000d	61,600d	54,400d	51,400d	29.9d	58.5d
			±2,200	±1,500	±1,400	±3,100	±2,400	±0.9	±0.3
3½% Nickel Steel.....	EJ-W-10	Quenched and Drawn	124,800g	105,400g	106,700g	102,800g	79,600g	21.6g	65.8g
			±5,200	±6,500	±6,600	±7,500	±2,600	±0.9	±1.7
5% Nickel Steel.....	CA-14.25	Annealed	121,800c	57,000c	56,300c	47,700c	46,300c	18.0c	25.8c
			±200	±1,300	±900	±2,200	±900	±0.7	±1.2
5% Nickel Steel.....	CA-W-11	Quenched and Drawn	132,700c	93,000c	96,000c	84,300c	80,000c	18.7c	40.5c
			±800	±1,300	±700	±2,900	±000	±.9	±2.3

Unless Otherwise Indicated, Each Value is Average of Two Determinations.
c—Average of Three Determinations.
d—Average of Four Determinations.
e—Average of Five Determinations.
f—Average of Six Determinations.
g—Average of Seven Determinations.

content and in physical properties has comparatively little effect.

Graphs "H" in Fig. 3 represent corrosion-fatigue in salt water. Additional experiments at lower stresses are needed to determine

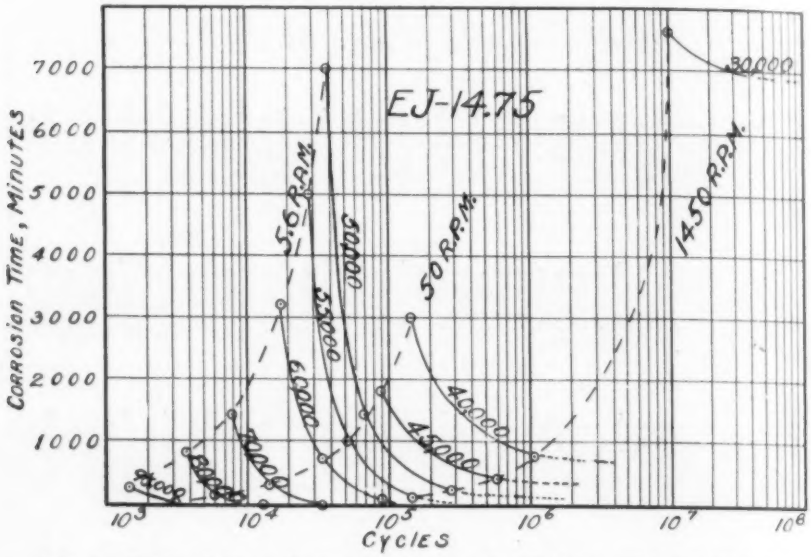


Fig. 5—Effect of Cycle Frequency on Corrosion-Fatigue: Material EJ-145.

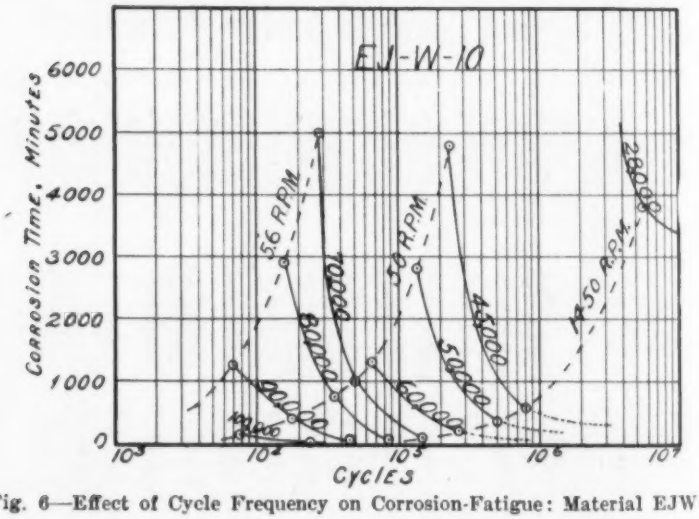


Fig. 6—Effect of Cycle Frequency on Corrosion-Fatigue: Material EJW-10.

corrosion-fatigue limits under these conditions. Evidence seems to indicate, however, that for salt water corrosion there is a corrosion-fatigue limit, though the limit is much lower than for fresh water. For annealed stainless iron, Material FH-16, the salt water corrosion-fatigue limit Scs is probably about 14,000 pounds per square inch. For the other stainless irons, Scs is probably not much

Table V

Comparison of Corrosion-Fatigue Limits with Endurance Limits and with Other Physical Properties

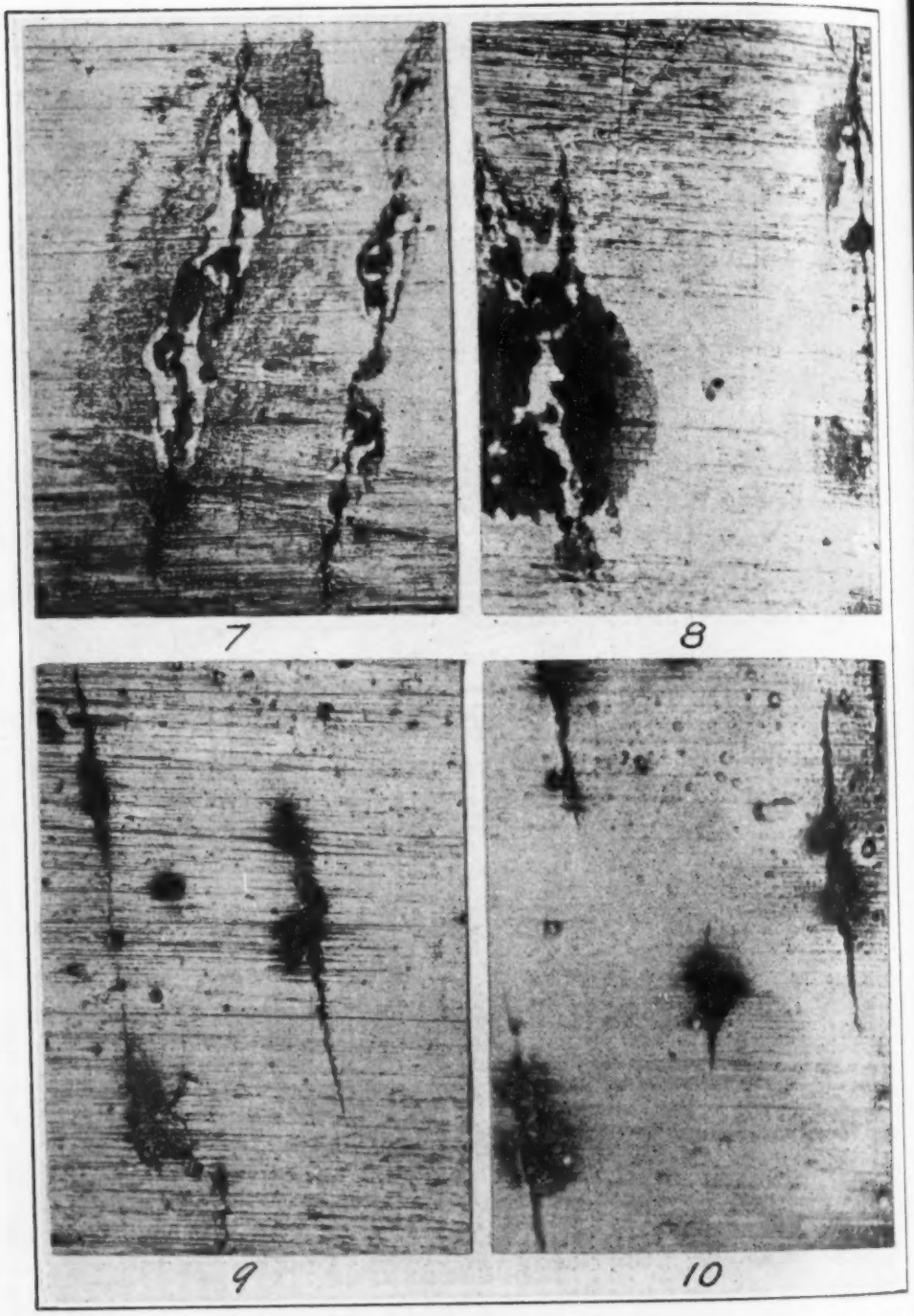
Elonga-
tion

Table V

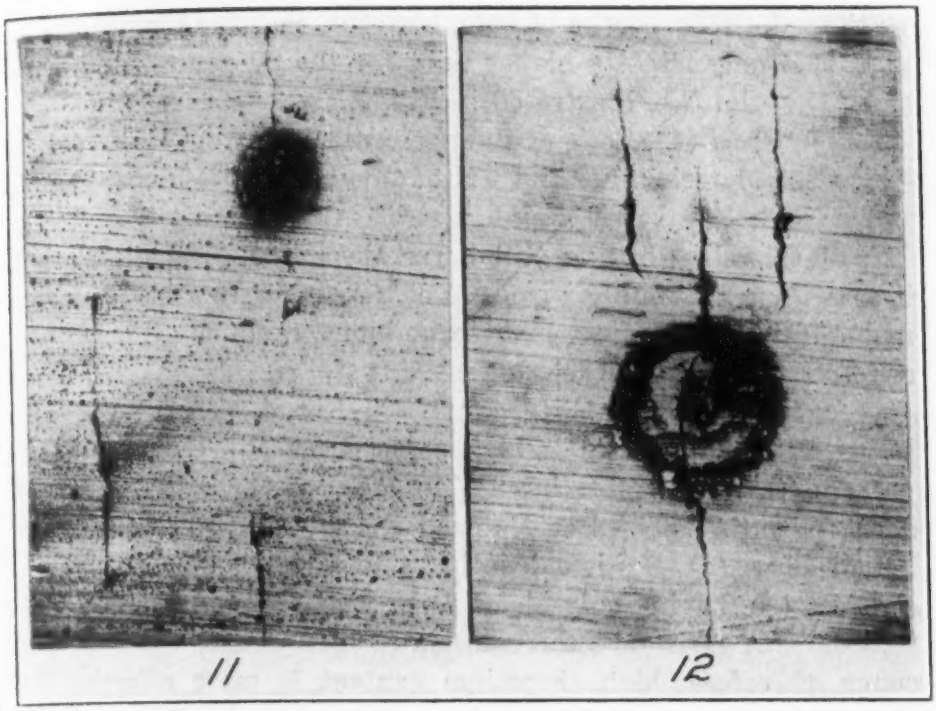
Comparison of Corrosion-Fatigue Limits with Endurance Limits and with Other Physical Properties

Material	Designation	Tensile Strength, Lbs. Per Sq. In.	Total Elongation in 2 In., Per Cent	Elongation in 2 In. at Maximum Load, Per Cent	Reduction of Area, Per Cent	Charpy Value, Ft. Lbs.	Endurance Limit, Lbs. Per Sq. In. SF	Corrosion-Fatigue Limits, Lbs. Per Sq. In.		Ratios	
								Sc	Scs	Sc to Sf	Scs to Sf
Stainless Iron	GO-18	61,500	41.0	21.0	67.5	33.6	39,000	30,000*	.....	0.77	...
Stainless Iron	GO-W-12	90,300	26.5	8.8	74.8	54.1	49,000	31,000	.....	0.63	...
Stainless Iron	FH-16	79,800	31.9	16.0	65.6	26.6	41,000	34,000	14,000	0.83	0.34
Stainless Steel	FJ-17	97,600	27.7	15.8	59.5	20.3	52,000	35,000	.....	0.67	...
Stainless Iron	GN-W-12	91,200	25.3	13.0	63.5	28.3	59,000	40,000	13,000*	0.68	0.22
Stainless Iron	FI-W-12	84,900	28.3	10.0	70.8	49.5	50,000	35,000	18,000*	0.70	0.36
Stainless Iron	GD	102,700	25.7	13.0	59.0	29.8	.....	33,000	.....	...	...
High Chromium Steel....	GA	110,900	22.5	11.0	41.5	3.3	.....	48,000	.....	...	...
Chromium-Nickel Steel ...	FL	125,300	45.5	45.0	53.2	59.2	50,000	50,000	25,000	1.00	0.50
Chromium-Nickel Steel ...	FLA	133,000	46.8	35.5	56.3	59.7	56,000	.....	.....	...	...
Chromium-Nickel Steel ...	EX	126,500	22.0	17.5	25.7	7.6	65,000	.....	.....	...	...
Chromium-Nickel Steel ...	EW	128,000	24.8	19.0	37.8	12.5	64,000	.....	.....	...	...
Chromium-Nickel Steel ...	EW-17	126,300	26.0	21.5	38.0	14.9	.....	51,000	.....	...	...
Chromium-Nickel Steel ...	EV	115,200	22.5	17.8	34.9	9.7	54,000	45,000	34,000	0.83	0.63
Chromium-Nickel Steel ...	EU	108,600	20.0	16.0	26.8	6.3	57,000	51,000	32,000	0.89	0.56
Chromium-Nickel Steel ...	ES	98,000	32.3	23.0	58.6	37.6	50,000	32,000*	.....	0.64	...
Chromium-Nickel Steel ...	FZ	85,200	43.0	40.0	50.0	45.0	.....	.....	15,000*	...	...
Chromium-Nickel Steel ...	ET	111,100	24.0	19.5	48.9	38.9	58,000	.....	.....	...	...
Chromium-Nickel Steel ...	ET-17	113,300	24.7	20.0	35.5	29.8	.....	42,000	20,000*	...	...
Chromium-Nickel Steel ...	FK	112,300	28.8	20.0	46.6	29.6	57,000	41,000	22,000	0.72	0.39
Ingot Iron	EK-17.5	42,300	47.0	25.0	72.5	12.3	21,000	15,000	.....	0.71	...
Ingot Iron	EK-W-7	43,900	45.5	22.5	75.0	35.2	24,000	20,000	.....	0.83	...
0.11% Carbon Steel	B-17.25	46,400	47.5	26.3	72.0	9.3	25,000	16,000	.....	0.64	...
0.14% Carbon Steel	G-W	70,100	30.5	17.0	73.1	60.8	36,000	23,000	.....	0.64	...
0.24% Carbon Steel	EL-16.5	59,200	37.8	24.5	59.0	12.3	27,000	16,000	.....	0.59	...
0.26% Carbon Steel	EN-W-9	84,500	28.2	12.5	64.7	42.9	39,000	23,000	.....	0.59	...
0.36% Carbon Steel	AG-15.5	79,200	31.3	18.8	48.7	22.4	34,000	25,000	.....	0.74	...
0.36% Carbon Steel	AG-W-9	103,600	25.0	11.0	57.8	37.8	52,000	19,000	.....	0.37	...
0.49% Carbon Steel	AE-15	82,900	27.8	14.0	43.7	14.5	34,000	23,000	.....	0.68	...
0.49% Carbon Steel	AE-W-10	110,900	24.0	9.0	54.3	19.4	53,000	20,000	.....	0.38	...
High Carbon Steel	EM-14.75	103,400	29.5	16.5	50.8	10.9	42,000	23,000	.....	0.55	...
3½% Nickel Steel	EJ-14.5	92,500	29.9	14.5	58.5	29.6	49,000	29,000	.....	0.59	...
3½% Nickel Steel	EJ-W-10	124,800	21.6	5.8	65.8	37.9	69,000	25,000	.....	0.36	...
5% Nickel Steel	CA-14.25	121,800	18.0	14.5	25.8	7.6	55,000	21,000	.....	0.38	...
5% Nickel Steel	CA-W-11	132,700	18.7	9.5	40.5	16.7	66,000	19,000	.....	0.29	...

Sc—Corrosion-Fatigue Limit, Fresh Water. Scs—Corrosion-Fatigue Limit, Salt Water. *Approximate.



Photomicrographs of Corrosion-Fatigue Spots on Steel Specimens. Fig. 7—A 0.36% Carbon Steel, Material AG-15.5; Stress, 29,000 Lbs. Per Sq. In.; in Water Throughout Test; 1,470,000 Cycles. Mag. 100x. Fig. 8—A 0.36% Carbon Steel, Material AG-W-9; Stress, 29,000 Lbs. Per Sq. In.; in Water Throughout Test; 1,608,700 Cycles. Mag. 100x. Fig. 9—A 3½% Nickel Steel, Material EJ-W-10; Stress, 58,000 Lbs. Per Sq. In.; in Water Throughout Test; 304,500 Cycles. Mag. 100x. Fig. 10—A 3½% Nickel Steel, Material EJ-W-10; Stress, 49,000 Lbs. Per Sq. In.; in Water Throughout Test. 471,000 Cycles. Removed at 471,000 Cycles. Mag. 100x.



Photomicrographs of Corrosion-Fatigue Spots on Steel Specimens. Fig. 11—A 3½% Nickel Steel, Material EJ-W-10; Stress, 65,000 Lbs. Per Sq. In.; in Water Throughout Test; 200,000 Cycles. Mag. 100x. Fig. 12—A 3½% Nickel Steel, Material EJ-W-10; Stress, 65,000 Lbs. Per Sq. In.; in Water Throughout Test; 200,000 Cycles. Mag. 100x.

higher. For Material GA, having over 20 per cent chromium, Scs cannot yet be predicted.

Corrosion-Fatigue of Chromium-Nickel Steels

Corrosion-fatigue of steels having relatively high percentages of both chromium and nickel is illustrated in Fig. 4. These steels are of three classes (a), those having high chromium (15 to 19 per cent) and medium nickel (7 to 9 per cent) content; (b), those having high chromium (15 to 19 per cent) and high nickel (16 to 25 per cent) content; and (c) those having medium chromium (5 to 11 per cent) and high nickel (22 to 35 per cent) content. In general the graphs are arranged in Fig. 4 in order of decreasing chromium and increasing nickel content. Consequently they are arranged in order of the three above mentioned classes.

For classes (a) and (b), the fresh water corrosion-fatigue limit Sc is about 50,000 pounds per square inch. For these steels, therefore, Sc is more than twice as high as for carbon steels, and about 50 per cent higher than for the stainless irons and steel in-

vestigated. It is worthy of note, however, that for Classes (a) and (b) Sc is only slightly higher than for the 20 per cent chromium steel, Material GA, illustrated in Fig. 3.

For Class (c), Sc is distinctly lower than for Classes (a) and (b). For Materials ET and FK of this class Sc is higher than for the stainless irons and stainless steel investigated. For Material ES, of this class having still lower chromium content. Sc is no higher than for stainless iron. For resistance to fresh water corrosion-fatigue, therefore, high chromium content is evidently more effective than high nickel content.

As illustrated by Graphs "H" in Fig. 4, the salt water corrosion-fatigue limit Scs is higher for Class (b) than for Classes (a) and (c). For Materials EV and EU of Class (b), Scs is evidently about 33,000. For Material FL of Class (a) and Material FK of Class (c), Scs is evidently below 25,000. For Material ES of Class (c), having only about 6 per cent chromium, Scs is below 20,000. For resistance to corrosion-fatigue in salt water or fresh water, therefore, high chromium content is more effective than high nickel content. Best resistance to corrosion-fatigue in salt water is obtained with high chromium and high nickel content.

Effect of Chemical Composition, and Physical Properties of Corrosion-Fatigue

For carbon steels, and for alloy steels having about the same corrosion-resistance, the corrosion-fatigue limit varies surprisingly little. Part of this relatively slight variation may be due to variation in corrosion-resistance. The obvious conclusion would be that, for such steels, the corrosion-fatigue limit is practically independent of chemical composition and heat treatment. Before the investigation was extended to corrosion-resistant steels, however, another explanation for the relative constancy of the corrosion-fatigue limit was possible. It appeared possible that the corrosion-fatigue limit is much more dependent on ductility than is the endurance limit. If increase in strength and accompanying decrease in ductility have equal and opposite influence on the corrosion-fatigue limit, this limit would remain practically unchanged. This possibility was discussed in the preceding paper.[4]

As the investigation was extended, however, this latter explanation became continually less probable. It was found that ad-

[4]See foot note (1) page 355.

dition of chromium and nickel in sufficient quantity to increase corrosion-resistance causes corresponding increase in the corrosion-fatigue limit. As illustrated by Figs. 1, 3, and 4, for each degree of corrosion-resistance there is a fairly definite level of corrosion-fatigue limits, which level is practically independent of wide variation in strength and ductility. As shown in Fig. 3, for example, stainless iron FH-16 and stainless steel FJ-17, having about the same chromium content, have practically equal corrosion-fatigue limits, though the stainless steel is superior to the stainless iron in tensile strength and ductility. As shown in Fig. 4, Materials EU and EW, having about equal chromium and nickel content have nearly equal corrosion-fatigue limits, though the latter is stronger and more ductile than the former. The effects of variation in tensile strength and ductility on the corrosion-fatigue limit, therefore, are insignificant in comparison with the effect of variation in corrosion-resistance. Nevertheless the effect of ductility on the corrosion-fatigue limit may not be so insignificant as the effect of ductility on the endurance limit.

As corrosion-fatigue depends on two factors, corrosion intensity and a stress range, it seems probable that the corrosion-fatigue limit depends on a strength factor as well as on corrosion-resistance. This strength factor evidently cannot be expressed in terms of the tensile strength or elastic strength of an alloy. One could account for a constant corrosion-fatigue limit for steels of about the same corrosion-resistance, by surmising that the strength factor on which the corrosion-fatigue limit depends, is the strength of the predominant phase, such as ferrite in steels. The corrosion-fatigue limit for carbon steels, however, is not entirely constant. A satisfactory hypothesis must explain not only the approximate constancy of the corrosion-fatigue limit for sorbitic steels having 0.03 to at least 0.5 per cent carbon, and for pearlitic steels having 0.3 to 1.1 per cent carbon, but also the definitely lower corrosion-fatigue limit for low carbon pearlite steels. The lower corrosion-fatigue limit of the low carbon steels is not readily explained by the hypothesis that the effective strength factor in resistance to corrosion-fatigue is the strength of the predominant phase.

It seemed possible that the lack of constancy in the corrosion-fatigue limit of carbon steels might be due to variation in ductility, or in toughness. For this reason, corrosion-fatigue limits obtained

from Figs. 1 to 4 have been assembled in Table V for comparison with results of tension and impact tests.

As shown in Table V, variations in ductility do not account for the variations in the corrosion-fatigue limit, Sc. For each annealed carbon steel the 'elongation' is greater and the 'reduction of area' is less than for the corresponding quenched steel. Though the corrosion-fatigue limit, for annealed low carbon steels is below, for high carbon steels it is above the corrosion-fatigue limit for the corresponding quenched steel. Variation in ductility of the carbon steels, therefore, is not parallel to the variation in the corrosion-fatigue limit.

Variations in impact value also are not parallel with the variations in corrosion-fatigue limit. As shown in Table V, the Charpy impact value for each quenched carbon steel is above the value for the corresponding annealed steel. It is worthy of note, however, that while the ratio between the Charpy impact values for quenched and for annealed material is about 3.0 to 6.5 for the low carbon steels, this ratio is only 1.3 to 1.7 for the higher carbon steels. The range of carbon content, therefore, in which sorbitizing treatment causes greatest improvement in Charpy impact value is the range in which this treatment causes greatest improvement in corrosion-fatigue limit. It seems possible, therefore, that the corrosion-fatigue limit depends somewhat on the 'notch toughness' of the material.

Comparison of the corrosion-fatigue limits and ratios for the other steels in Table V merely confirms the conclusion that the effect on the corrosion-fatigue limit of the physical properties determined by the usual tension and impact tests, is almost negligible in comparison with the effect of corrosion-resistance.

Nevertheless, though corrosion-resistance is the most conspicuous factor, it is probably not the only important factor in resistance to corrosion-fatigue. There may be an important strength factor that has not yet been discussed. The possibility suggests itself that this strength factor may be the modulus of elasticity. If modulus of elasticity and corrosion-resistance are the two important factors, this would account for the constancy of the corrosion-fatigue limit for sorbitic steels and for pearlitic steels having more than about 0.3 per cent carbon. The lower corrosion-fatigue limit of the pearlitic low carbon steels might then be explained by the surmise

that for such steels the determining strength factor is the elastic strength of the unstrengthened ferrite regions.

Whether the modulus of elasticity or some other fundamental property is the effective strength factor, for sorbitic steels and all except low carbon pearlitic steels, cannot be decided at present. Further discussion of this subject will be deferred until after presentation in Part II, of results of corrosion-fatigue tests of non-ferrous metals.

Acknowledgement is hereby made for the encouragement received in this work from Captain H. C. Dinger, U. S. N. Officer-in-Charge, U. S. Naval Engineering Experiment Station, and of the assistance received from G. F. Wohlgemuth, associate metallurgist, from J. L. Basil and A. P. Vandermast, laboratorians, and from J. K. Amoss, toolmaker, at the Naval Experiment Station. The generous cooperation of the American Rolling Mill Co., in furnishing material is also acknowledged.

The Author

D. J. McAdam, Jr., received the degree of A. B. and A. M. from Washington and Jefferson College. He spent two years in a post-graduate study of chemistry at Harvard and two years at the University of Pennsylvania. He received the degrees of M. S. and Ph. D. from the latter institution. After several years spent in teaching chemistry at Lehigh University and in other positions, he assumed his present position as metallurgist, at the U. S. Naval Engineering Experiment Station, Annapolis, Md. He is a member of several technical and scientific societies and author of a number of papers on metallurgy. Dr. McAdam is a member of the American Society for Steel Treating and has taken an active part in contributing scientific papers at a number of the annual conventions of the Society.

D. J. McADAM, JR.

DISCUSSION

Written Discussion: By T. McLean Jasper, director of research, A. O. Smith Corporation, Milwaukee.

It is quite clear to the writer that the author has drawn attention to an interesting discovery. Although the writer has been invited to discuss this paper, he feels great difficulty in doing so owing to his lack of familiarity with the phenomenon described. Discussion without constructive criticism or supplementary facts has little value. On the main issues of the paper therefore the writer is unable to add anything.

There are a few points however which it might be helpful if attention were drawn to them, if for no other reason than to make clear certain things which might appear to the reader as needing further researches or clearer descriptions.

From the paper it is understood that the only mediums used for corrosion are two different waters. This suggests that similar phenomena with possibly different endurance limit would be found if for instance the specimens were run in sea water, acid mine water and possibly quite different values would accrue if distilled water were used. Also waters at different temperatures might produce different results from cold water. What applies to various waters might also apply to various lubricating oils or any other medium which is appropriately in contact with metal in engineering work.

The author in his attempt to discuss stresses above the yield point for a bending specimen seems to ignore the fact that the ordinary bending formula does not apply for stress values above this point, that is, $S = \frac{Mc}{I}$ is only true within the elastic range of the material in which the stress-strain diagram is a straight line. The writer drew attention to this fact in a previous discussion of another paper by the author. In this case the torsion specimen and the appropriate mechanics formula was under consideration. When the ultimate strength is approached in a ductile bending specimen the formula given is far from appropriate for the true stress condition. For the above reason the writer does not think that the author's statement, "By water cooling it is possible to extend the stress-cycle line above the nominal tensile strength of the material," is correct.

It is not quite clear to the writer how the author attributes to the modulus of elasticity a possible connection with corrosion resistance. Some enlightenment on this would be appreciated by the writer. The modulus of elasticity is not considered by the writer as a strength factor but rather as an elastic factor.

Written Discussion: By J. B. Kommers, associate professor of mechanics, University of Wisconsin, Madison, Wis.

Doctor McAdam is to be congratulated on the admirable work which he has done on corrosion-fatigue as represented by his June paper before the American Society for Testing Materials and by the present paper. The papers are of the greatest interest from two viewpoints: (a) the theoretical point of view; and (b) the pratical point of view.

On the theoretical side these papers are of importance because at the present time there is no commonly accepted hypothesis which explains in detail the exact mechanism of fatigue failure; and Dr. McAdam's discussion will no doubt have an important influence in forwarding the formulation of this much desired hypothesis.

On the practical side the importance of Dr. McAdam's discussions is obvious. It is sufficient to mention merely the one fact that his tests show that the corrosion-fatigue limits of all sorbitic carbon steels and pearlitic carbon steels having about 0.3 to 1.1 per cent carbon, are about the same. A single fact like this, which is only one of the results shown by his tests, is startling, to say the least.

A further practical result of these tests from the standpoint of the fatigue investigator is the fact that another important influence on the endurance limit of metals and alloys has been isolated, and the investigator will now be careful to see that corrosion-fatigue will not be overlooked, both when investigations are planned, and also when the results of tests are to be interpreted.

It seems clear that the factor of concentration of stress at the spots where corrosion has occurred is one which may help to explain the lowered endurance limit which has been shown under corrosion-fatigue. The large percentage effects on endurance limit due to corrosion-fatigue recalls to the present writer's mind the similar effects which may be obtained by notches and sudden changes in cross-section. Perhaps it may be possible, by a properly devised series of experiments, to establish the fact that the corrosion-fatigue effects result from the production of a situation in which local concentration of stress introduces its deadly work. It would at least be interesting to see whether such a correlation of results is possible.

Written Discussion: By N. L. Mochel, metallurgical engineer, Westinghouse Electric and Manufacturing Company, South Philadelphia Works.

The author is to be congratulated on the splendid and important work covered in this paper. It marks a distinct step forward in the field of fatigue testing, in that it considers in addition to stress that other factor, corrosion, which is so often present in the utilization of materials.

The numerous materials used in the investigation cover well the range of carbon steels, 3½ per cent nickel steels, and the present broad field of corrosion-resistant steels. Especially is the author to be congratulated on the thoroughness with which he has covered this latter field. It is to be regretted that the 5 per cent nickel steel was not of the low-carbon type employed in large quantities for turbine blading and casehardened parts. Such low-carbon (under 0.10 per cent) 5 per cent nickel steels have probably a higher ratio of endurance limit to tensile strength than other alloy steels, they offer greater resistance to corrosion than the high carbon type used in the investigation, and it would be of interest and value to determine how such a steel would behave under corrosion-fatigue.

The results in general rather indicate that resistance to corrosion is the matter of prime importance. In other words, nothing has been added to ordinary fatigue tests other than a corrosive agent, and the reduction of the en-

durance limit to the "Sc" and "Scs" corrosion-fatigue limits can only be due to the effect of the corrosive agent. Let us consider the ordinary carbon steels. Corrosion resistance certainly decreases with increased carbon content, and might not the decreasing resistance to corrosion of the higher carbon steels be sufficient to overcome the natural higher endurance values of such steels, and bring them all to nearly the same level. In the chromium steels, the author especially refers to stainless steel FJ-17, and stainless iron FK-16 (we assume FH-16 is meant), as being equal in chromium content and having the same corrosion fatigue limit, yet FJ-17 is superior in tensile strength and endurance limit. But stainless iron FH-16 is certainly superior to stainless steel FJ-17 in resistance to oerrosion, in the annealed conditions in which they were tested, and this difference in resistance might well be sufficient to overcome the higher endurance limit. Then again, the high chromium steel GA is definitely known to be more resistant to corrosion than the lower chromium types, and we might well expect higher "Sc" values.

Passing to the nickel-chromium types of rustless steels, the (a) and (b) classes are known to be more resistant to corrosion by water than the straight chromium steels, and could be expected to show higher "Sc" values. Some of the steels in the (c) class are superior to the ordinary stainless irons and steels and would naturally give higher results, although steels in this (c) class of the ES and FZ types are in many cases no better if not inferior to the stainless irons, in fact they will rust in the atmosphere.

As to salt water, it is well known that the class (b) steels are superior in the matter of corrosion resistance, and it would be expected that they would give higher "ScS" values. In general, it would appear that chemical composition has an important point in the matter of corrosion-fatigue, but only insofar as the variation in composition results in greater resistance to corrosion.

The results further indicate that there must be a time element, as evidenced by the "B" curves actually lying above the "A" curves, for the tests at high stresses and naturally of short duration. It appears, however, that this time element is merely that of time for corrosion to take place.

The writer feels that the author has not brought out sufficiently that other factor of the title—heat treatment. It is well known that heat treatment is a most important point in the corrosion resistance of steels of the stainless steel type, such as material FJ. The treatment given was not one designed to bring out maximum resistance to corrosion. Would heat treatment such as to bring out maximum resistance to corrosion result in an increased "Sc" value. In general, the writer feels that heat treatment may have an important place in the matter of corrosion-fatigue, but only insofar as the variation in heat treatment results in greater resistance to corrosion.

The author has shown in the previous and present paper that severe corrosion prior to the stressing lowers the fatigue resistance much less than slight corrosion simultaneous with fatigue. Thus, the weakening effect of pits or etched and corroded areas is not the solution of the matter; the weakening effect of such can probably be disposed of in the same way as notches, scratches or other surface imperfections which are known to reduce the endurance

limit in varying degrees according to their magnitude. It would appear that we must search for a solution in the effect of the corrosive agent upon the crystal boundaries or the slip bands of the metal, at the same time as the stresses are being applied. This thought immediately raises the question, not covered in the paper, as to whether failure in its start or entirety was intercrystalline. Intercrystalline failure from combined stress and corrosion is not a new matter; "season cracking" of nonferrous alloys, so-called "embrittlement" of boiler plate, and the baffling failure of aluminum bronze and 30 per cent nickel steels in turbine installations abroad, are but a few examples of failure from combined stress and corrosion. But it is important that both stress and corrosion must be present for failure to occur, although it is well known that the corrosion may be slight.

There is one other important feature, the nature of the corroding medium. The results clearly show that salt water lowers the corrosion-fatigue limit below that for fresh water. It is of course well know that the straight chromium steels resist action by some agents better than the nickel-chromium steels. If materials were subjected to test or service under such conditions, might we expect the results to be reversed, that is the straight chromium steels to show higher corrosion-fatigue values than the nickel-chromium steels.

Written Discussion: By H. F. Moore, Research professor of engineering materials, University of Illinois, in charge Investigation of the Fatigue of Metals.

Dr. McAdam has added yet another perplexity to the lot of the student of the fatigue of metals. We have had to consider strength, microscopic structure, minute flaws and inclusions, and now Dr. McAdam shows us that we shall have to consider chemical action also.

For some time there has been a general feeling among engineers that corrosion and fatigue were mutually accelerative actions.* However, the experiments of Dr. McAdam (and the much briefer series of experiments by R. R. Moore) are the first quantitative results we have on this phenomenon. They are rather startling, and constitute a distinct addition to our field of thought about fatigue of metals. Perhaps the most startling suggestion in Dr. McAdam's paper is that under repeated stress slight corrosion action may go far in neutralizing the beneficial effects of heat treatment of steel.

Of major importance is the conclusion that stress and corrosion must go on together in order to produce these serious effects. Dr. McAdam has performed a distinct service in giving us some definite experiments in a field in which there had previously been only speculation and inconclusive short-time tests.

His paper re-enforces the fact, already known, that corrosion and fatigue are mutually accelerative in their destructive action, and brings out the startling fact that *under repeated stress* slight corrosive action may go far in reducing the fatigue strength of steel and in neutralizing the beneficial effects of heat treatment.

Of special interest is his tentative conclusion that ductility is a minor factor in increasing resistance to corrosion under stress. This conclusion runs

*See *Engineering News-Record*, September 3, 1925, page 376, "Stress Repetition and Fatigue in Steel Structure." Last paragraph.

parallel to the generally accepted conclusion that ductility is a minor factor in determining fatigue strength under non-corrosive conditions.

The suggestion that the Charpy (or Izod) test may be of some value in indicating resistance to corrosion-fatigue is also of interest, and may be considered to run parallel to the suggestion made by the speaker that the Charpy test may give an indication of the ability of a metal to offer increased resistance to the destructive action of notches and grooves.

Written Discussion: By J. M. Lessells, Westinghouse Electric and Manufacturing Company, East Pittsburgh.

The paper by D. J. McAdam undoubtedly throws a great deal more light on the effects of corrosion, and the author should be complimented on his work. There are several points, however, which should be mentioned.

Fatigue tests as they are ordinarily conducted duplicate in large measure the conditions occurring in service. The surface finish is representative of that obtaining on actual finished machined parts and the speed of testing embraces those ranges of speed encountered in practice. The tests themselves therefore supply data which can be directly used in design and are fundamental in character. In the tests now described by Dr. McAdam, however, the corrosion conditions are so severe that it is doubtful if they will often be met in service. The speaker does not wish in the slightest sense to deprecate the work of Dr. McAdam, but in the interest of designers would it not be advisable to mention this point.

On page 378 mention is made of the possible effects of modulus of elasticity. If this were true would we not expect a rigid relation between modulus of elasticity and endurance limit, which high temperature tests show not to be true. It is to be hoped that this work will be continued by Dr. McAdam.

Oral Discussion

R. E. CHRISTIN: Does the author imply that running water on dies under fatigue, such as dies for heading hot bolts, hastens the failure of the dies?

DR. MCADAM: It would if they are stressed above the corrosion-fatigue limit.

R. E. CHRISTIN: Does the corrosion-fatigue act along with the endurance limit?

DR. MCADAM: Yes. That was shown in annealed high carbon steel having about 1.1 per cent carbon, which failed under conditions of corrosion and fatigue at lower stresses than it would have failed if the corrosion had not been present.

R. E. CHRISTIN: Could you tell me if high carbon chromium steels would stand less endurance than the tungsten steels in running water?

DR. MCADAM: We did not try any tests on tungsten steels. In general, I think the chromium steels have a higher resistance to corrosion than the tungsten steels. If that is the case, one would expect them to have a higher corrosion-fatigue limit.

R. E. CHRISTIN: High carbon chromium steels will stand more shock with

the running water on them than the tungsten steels, but we would like to know whether the water on the tungsten steel has a corrosive effect on it.

DR. MCADAM: I think it has.

R. E. CHRISTIN: Would it be better to use the tungsten steels without running water?

DR. MCADAM: You could run them at higher stress without water without causing a failure.

E. E. THUM: Early in the investigations of fatigue, the enormous influence of the surface finish on the test results was noted. Only recently has it come to our attention that this matter of surface finish and the matter of minute internal inclusions are closely related. Mr. McAdam's recent startling discovery of the influence of surface corrosion, starting at these inclusions, has proven this. Mr. Lucas' pictures, which were shown today, emphasize again the fact that fatigue is related to "quality" in the metal more than anything else.

It is now of great importance, it seems to me, that some man with a gift of coordination and interpretation study the enormous mass of experimental data which is now available and do some theorizing. We are ready for that, I believe, because some simple thing, such as Mr. McAdam's discovery of corrosion at the surface, is likely to throw three-quarters of the data which we have accumulated with such great patience into the discard. What good, for instance, does it do us to know that the fatigue resistance of a hardened and annealed steel is, we will say, four-tenths of its Brinell hardness, if just as soon as it runs a little wet, the fatigue resistance is no longer four-tenths but is approximately 0.15? If we knew more about the "why" of fatigue, I believe we would be in better position to map out new experiments on commercial steels used at present.

Perhaps it has occurred to some of you, as you looked at Mr. Lucas' pictures of inclusions in Armco iron at several thousand diameters of magnification, as it did to me, that that picture, if you took away the crack, looks about like what a highly magnified volume of gas might look like. It also seems that the path of the fracture is controlled by these dispersed particles. Now, mathematicians have started out with a few fundamental propositions about the action of gas molecules, and have built up a kinetic theory of gases so they have been able to predict results by purely mathematical means, which have later been checked by experiment. They also have verified many experimental results and indicated where they might be slightly in error.

Is there not a possibility that, given some pure iron and some data on its fatigue properties, and enough of the higher mathematical analysis and the theory of probability, we would have the raw materials whereby we would be able to get some real insight into what goes on inside a piece of commercial metal when we start to test it under rapidly alternating stresses?

Therefore, I would like to suggest the apparent paradox that a good way to extend our knowledge of fatigue is to get behind some fundamental research on the properties of pure iron.

E. S. TAYLERSON: On casual examination, the shape of these curves

indicates a double logarithmic relationship. If both variables were plotted on logarithmic coordinates, the observations might fall on a series of straight lines.

DR. H. STYRI: I would like to mention in this connection some experience that we have had on ball bearings. From repeated failures we have drawn the conclusion that when the bearings have been subjected to corrosion, the resistance to fatigue is less. Of course, it is impossible to tell to what extent the corrosion has influenced this property, because the amount of corrosion is different. But we have found many cases where corrosion, due to wrong lubricant, for instance, or due to the presence of humidity, has certainly influenced the life of the bearings. That is just an illustration of the importance of Dr. McAdam's investigation.

A. C. JONES: Inasmuch as parkerizing seems to be an economical method of preventing corrosion, it might be that tests on parkerized materials would show a high value for corrosion fatigue resistance as compared to plain steel. Of course chromium plating as a skin would more effectively resist corrosion; but the resistance of parkerized surfaces might be sufficiently great to make it a practical proposition, for that service where chromium plating is too expensive.

A. L. DAVIS: Mr. Chairman, this question of corrosion as affecting fatigue might possibly be attacked by protecting the specimen with some thin coating such as chromium. It has been found in tools that the life is increased by a small thin coating of chromium. I would make the suggestion that perhaps the way is open on fatigue tests to put on a coating (of only perhaps a few ten thousandths) to see what effect, if any, it has. On tools working under corrosive conditions, it has been found that the life is increased by a thin coating of chromium,—chromium that could not presumably do anything more than act as either a lubricant or a protection against corrosion.

CHAIRMAN JEFFRIES: Before we ask Dr. McAdam to close, I would just like to call attention to two things. One is Prof. Jasper's statement to the effect that the endurance limit, or rather the stress at failure obtained by Dr. McAdam being higher in the cases of only a few cycles than the measured tensile strength, entirely due to the fact that permanent deformation takes place and that the stresses calculated, assuming that the material is entirely elastic, does not necessarily follow. That is, the calculated stress is, we will say, fairly accurate as long as the material is elastic, but as soon as the material ceases to be elastic, then the calculated stress is higher than the real stress. It is easily possible to obtain stresses in metals higher than the measured tensile strength. That is obtained regularly in notches, as has been known for many years, and as was pointed out quantitatively very nicely by R. R. Moore at the June Meeting of the A. S. T. M. in Atlantic City, when he obtained actual unit stresses of 25 to 30 per cent higher than the ordinary tensile stresses in threaded bars. The thing to be remembered there is simply the measured tensile strength is only the quantity obtained when the specimen breaks with considerable reduction of area and elongation. That tensile strength is specifically associated with a certain amount of elongation, so that a piece of copper wire, for example, that already has been severely over-

drawn, may have an elongation of only one per cent in the ordinary tensile test, yet if drawn through wire drawing dies the elongation may be many hundredths of a per cent without rupture.

The same thing is true in coiling. A piece of cold drawn wire with very little elongation on the tensile test, can be coiled on high tension around a mandrel and can be stretched easily as much as ten to 12 per cent without rupture. So that the percentage of elongation is a function of free rupture and the tensile strength is a function of rupture, with considerable extension and with reduction of area. So it is easily conceivable that the actual stresses that Dr. McAdam had were above the measured tensile strength of the material.

The other point that I wish to call brief attention to is that the non-ferrous people think they have, for example, real copper, and while the work on pure copper and certain other pure metals has not been as extensive as it has in steel, yet it seems not to have thrown much light on this question of the mechanism of fatigue failure.

DR. MCADAM: In line with what Dr. Jeffries said about Prof. Jasper's discussion, I should like to say a few words. A person reading Prof. Jasper's discussion would get the idea that in the paper there was considerable discussion of the formula to be used in the best specimen in order to get the stress. There was no such discussion, and the only sentence that I can find along that line is one which says: "By water cooling it was possible to extend the stress-cycle line above the nominal tensile strength of the material." The word "nominal" covers really all of Prof. Jasper's discussion.

I am at a loss to understand Prof. Jasper's discussion especially, because in the publications of Professors Jasper and Moore, they frequently used the same formula below and above the elastic limits. Moreover, for annealed metals the entire stress-cycle curve is above the elastic limit. Yet, I believe, they used the formula in calculating nominal stresses for all their graphs. I agree with Dr. Jeffries that it may be possible to obtain actual stresses above the tensile strength of the material, although the actual stresses are probably somewhat lower than the nominal stresses.

As described in a previous paper, we ran specimens of monel metal at the nominal stress of 175,000 pounds per square inch, whereas the tensile strength of that material was 135,000. So it is quite possible that the material was actually stressed above its tensile strength.

In an effort to determine whether the corrosion-fatigue failures are inter-crystalline, we examined a number of specimens. We find that when the crack is between two widely separated inclusions it may follow for a short distance the inter-crystalline boundaries; but it seems to prefer the nonmetallic inclusions. In its path from one inclusion to another, however, it may deviate and follow inter-crystalline boundaries for a short distance.

Mr. Lessells doubts whether the corrosion fatigue experiments in fresh or salt water are paralleled by conditions in service. I think that it is important not to over-estimate the importance of corrosion fatigue in water;

but in spite of that, there are many instances where metals in service are in contact with fresh or salt water.

Mr. Taylorson asked whether, in Figs. 5 and 6, plotting the time element and cycles on a logarithmic scale would give a straight line. We tried that and we find that sometimes straight lines and sometimes curves are obtained.

Dr. Styri spoke of the corrosion fatigue of ball bearings. That was quite a problem in our experiments. The stream of water got into the ball bearings of the machines, and we had a corrosion fatigue of the ball bearings as well as the specimen.

Mr. Thum rather seems to minimize the effect of the importance of experiments on fatigue of metals.

I believe the best way to arrive at a satisfactory theory is to make extensive and carefully planned experiments.

Author's Written Closure of Discussion

My reference to modulus of elasticity as a possible factor in corrosion-fatigue was based on theorizing about the physical factors involved. The data presented in the paper would seem to indicate that the corrosion-fatigue limit depends on corrosion-resistance and on at least one physical property. To explain the relatively slight variation in corrosion-fatigue limit of carbon steels with wide variation in physical properties, and especially to explain the effect of cold working on corrosion-fatigue (to be discussed in Part II) two hypotheses suggested themselves. It seemed possible that the physical factor is either the strength of the predominant phase or the modulus of elasticity. Professor Jasper expresses surprise at the suggestion that modulus of elasticity may be a factor. To illustrate my idea about the possible influence of modulus of elasticity let us imagine two metals equal in tensile strength, elastic limit, ductility, and corrosion-resistance, but unequal in modulus of elasticity. Does it not appear possible that the metal with lower modulus of elasticity would have the lower corrosion-fatigue limit? In other words may not the surface strain be the important physical factor? The suggestion was intended to be merely tentative.

To account for the phenomena of corrosion-fatigue the most obvious hypothesis is the stress concentration hypothesis. The implications of this hypothesis have been discussed in this paper and in the previous paper.[1] To explain the phenomena by this hypothesis, however, is not so easy as it might appear. When corrosion-fatigue cracks have formed, there is obviously stress-concentration. But so is there stress-concentration after ordinary fatigue cracks have formed. The important fact to be explained is the lowered stress at which corrosion-fatigue cracks start. It is conceivable that the corrosion-fatigue limit is the stress above which the mutually enhancing influences of corrosion and fatigue cause penetration of the metal even at regions where the original concentration of stress or corrosion is extremely slight. Such penetration could be considered either as corrosion-pitting, accelerated by fatigue, or as fatigue accelerated by corrosion pitting, below the corrosion-

[1] D. J. McAdam, Jr., "Stress—Strain—Cycle Relationship and Corrosion-Fatigue of Metals," Proceedings, Am. Soc. Test. Mat., Vol. 26, Part II, 1926.

fatigue limit. According to this hypothesis, uniform films are formed and the metal is not penetrated.

This obvious hypothesis would explain the lowered fatigue resistance of metals subjected to simultaneous fatigue and corrosion. To explain by this hypothesis the additional fact that under corrosion-fatigue the effects of heat treatment and composition of carbon and ordinary alloy steels are practically obliterated, it is necessary to assume that the elevating effect of the increased strength on the corrosion-fatigue limit is balanced by the depressing effect of accompanying decreased ductility. As mentioned in the paper, and by Mr. Mochel in his discussion, variation in the corrosion-resistance of these steels may have some influence on the corrosion-fatigue limit. Mr. Mochel's suggestion, however, that variation in corrosion resistance of the carbon and ordinary alloy steels is sufficient to balance the effects of varying strength on the corrosion-fatigue limit does not seem plausible. As Speller points out,[2] the variation of corrosion-resistance in such steels in water is slight. It would seem more probable that the chief influence opposing the effect of increase in strength is the effect of accompanying decrease in ductility.

As stated in the paper, however, the stress-concentration hypothesis does not seem adequate to explain all the phenomena presented in the paper. Additional results to be presented in Part II also seem to confirm the conclusion that the stress-concentration theory is inadequate as an explanation of corrosion-fatigue.

Mr. Mochel discusses extensively the effects of varying corrosion-resistance. Much of his discussion is actual paraphrasing of the language and implications in the paper. His intention was doubtless to emphasize the importance of this phase of the subject. This paper and the previous paper,[1] however, repeatedly emphasized the fact that heat treatment of carbon or alloy steels apparently affects the corrosion-fatigue limit only as it affects corrosion resistance. It is nowhere implied, morever, that it would not be possible by other heat treatments to obtain higher corrosion-resistance and hence higher corrosion-fatigue limits for stainless iron and steel. The heat treatment given to the samples described in the paper was adapted to produce properties suitable for turbine blading or other machinery parts.

Mr. Mochel suggests the probability that corrosion-fatigue is an intercrystalline attack. In a paper on a new field there are always many phases of the subject that are not discussed. This does not necessarily mean that they have not occurred to the author. Many phases are omitted because haste is necessary in preparing the paper at a definite time, or because of lack of space, or because the author is not yet ready to present his views. The question of intercrystalline attack has been investigated continually throughout to the course of the corrosion-fatigue investigation. The microscopic investigation of this subject is not so easy as it might appear. For this reason it seemed desirable to defer a more complete discussion to a later paper.

In the September, 1926, issue of *The Metallurgist* (supplement to *The Engineer*) is a review of my paper which emphasizes the fact that I have

[2] F. N. Speller, "Corrosion—Causes and Prevention," McGraw-Hill Book Co., 1926.

omitted reference to a paper published by Haigh in 1917,[3] in which paper are some experiments on simultaneous corrosion and fatigue. In some experiments described in Haigh's paper, brasses and bronzes were subjected to alternating stress while in contact with ammonia, salt water, and hydrochloric acid. He found slight lowering of the stress-cycle graph when Muntz metal and naval brass were etched with ammonia, but found no such lowering with the other combinations of metal and corrosive agents. As his experiments were extended to only 1,500,000 cycles, his results were not quantitative and neither corrosion-fatigue limits nor true endurance limits were obtained.

Haigh points out, however, that even the slight damaging effect of ammonia on brass is not produced unless corrosion and fatigue are simultaneous. Although Haigh suggests the possibility that corrosion may affect unfavorably the endurance properties of metals in service, his results gave no indication of the great and general effect of even slight corrosion when simultaneous with fatigue. His experiments, however, made less impression than they deserved. Seven years later Gough's comprehensive book, "The Fatigue of Metals,"[4] made no mention of corrosion. I had overlooked Haigh's work, and the absence of any reference to corrosion in Gough's 1924 book led me to believe there had been up to that date no important investigation of corrosion-fatigue.

[3]B. P. Haigh, "Experiments on the Fatigue of Brasses." Journal. Inst. of Metals, 1917, No. 2, pp. 55-86.

[4]H. J. Gough, "The Fatigue of Metals," London: Scott, Greenwood & Son, 1924.

THE DECOMPOSITION OF THE AUSTENITIC STRUCTURE IN STEELS—Part II.*

The Decomposition of Austenite in Liquid Oxygen

By Oscar E. Harder and Ralph L. Dowdell

Abstract

This paper is a continuation of the research on the decomposition of the austenitic structure in steel and pays particular attention to the decomposition of austenite in liquid oxygen. Six steels were included in the investigation: 1, a cobalt-chromium magnet steel; 2, Hadfield manganese steel; 3, a high carbon high chromium steel; 4, a high speed steel; 5, a 22 per cent nickel steel; and 6, a hypereutectoid carbon steel.

Specimens have been immersed in liquid oxygen for various periods of time and the progress of the decomposition followed by changes in hardness, microstructure, and specific gravity. A general correlation in these changes has been found. A marked difference in the stability of the austenitic structure at low temperatures is clearly shown. Consideration is given to the influence of the stresses at liquid oxygen temperature on the decomposition of austenite.

IN order to study the effect of extremely low temperatures on the decomposition of austenite, a series of tests was made in which austenitic steels[3] were stored in liquid oxygen for various periods of time, after which treatments they were examined as to hardness, microstructures and densities.

The steels used in this series of tests were heat treated so as to put them in the austenitic condition. Pieces of steels Nos. 1 to 6 inclusive of about one cubic centimeter in size were kept submerged in liquid oxygen for various periods of time.

*This and the following articles on The Decomposition of the Austenite Structure in Steel are based on a manuscript submitted by Ralph Lewis Dowdell in partial fulfillment of the requirements of the Graduate School of the University of Minnesota for the degree of Doctor of Philosophy. O. E. Harder, in charge of research. The introductory article of this series appeared in the January, 1927, issue of Transactions.

[3]The steels used in this investigation were Nos. 1, 2, 3, 4, 5 and 6 which were described in an earlier paper, Transactions, American Society for Steel Treating. Vol. XI p. 219, 1927.

A paper presented before the eighth annual convention of the Society, Chicago, September 20 to 24, 1926. Of the authors, Dr. R. L. Dowdell is assistant professor of metallography and Dr. O. E. Harder is professor of metallography, University of Minnesota, Minneapolis.

Changes in Hardness—After the various cumulative immersions, hardness measurements were made with a scleroscope to show the progress of the decomposition. The results of these tests are shown in Table IV.

Table IV

Effect of Liquid Oxygen Temperature on the Scleroscope Hardness of Austenitic Steel

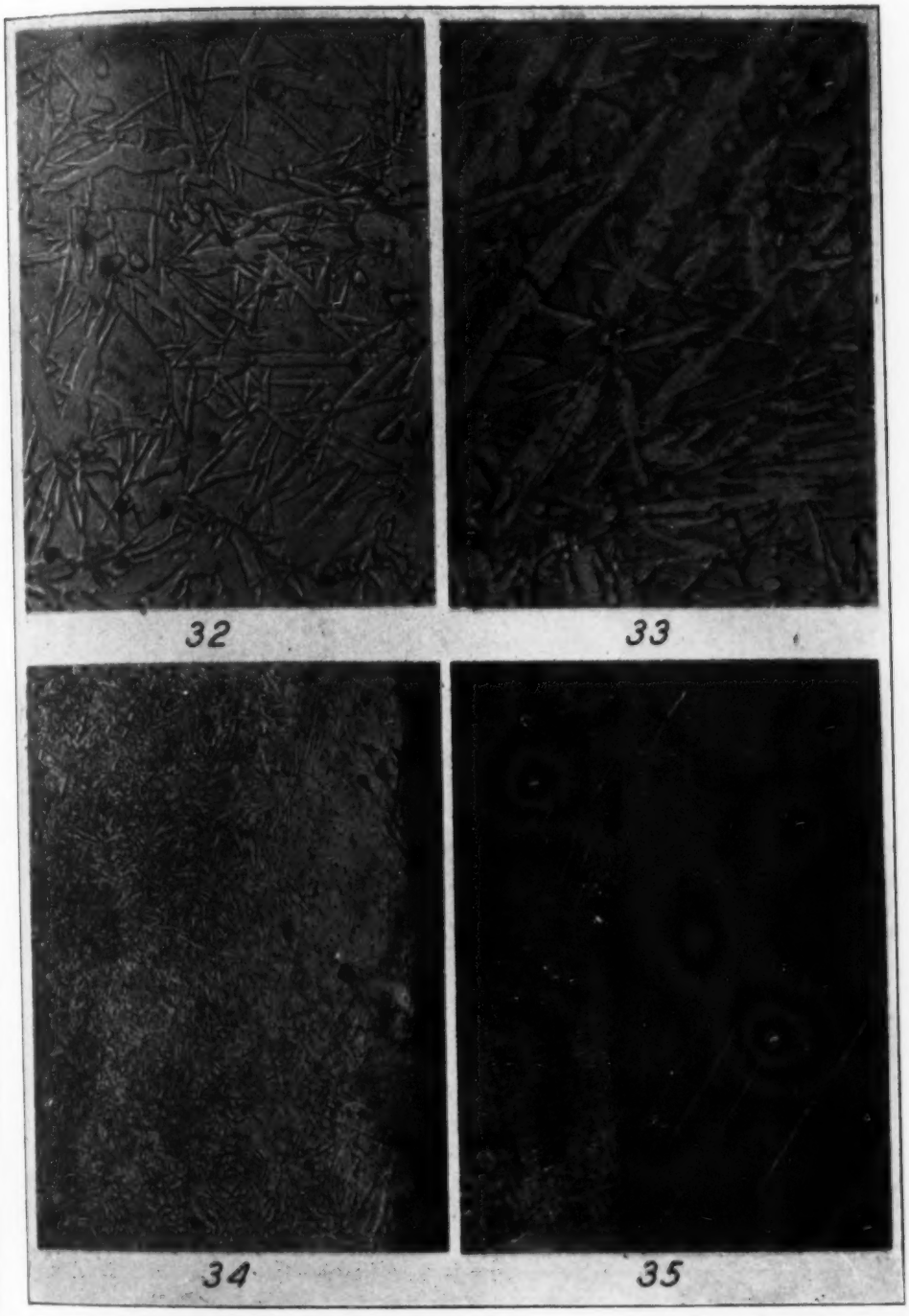
Treatment	Scleroscope Hardness Numbers. Steel No. 1	Steel No. 2	Steel No. 3	Steel No. 4	Steel No. 5	Steel No. 6
Original (as quenched)	44.5	30.0	47.3	53.5	45.1	77.9
Submerged 12 hrs. at −180°C.	74.3	38.0	76.1	55.0	49.6	95.3
Resubmerged 24 hrs. at −180°C.	79.4	34.2	75.4	54.6	53.0	96.4
Resubmerged 48 hrs. at −180°C.	79.5	32.6	74.7	55.1	56.2	98.3
Resubmerged 24 hrs. at −180°C., with bell vibrator	79.8	30.0	79.0	58.1	58.3	98.2
Resubmerged 25 times from −180°C. to room temperature	82.4	30.4	79.4	60.0	58.6	99.2
Resubmerged 10 times from +100°C. to −180°C. followed by holding at −180°C. for 1½ hrs. allowing the liquid oxygen to evaporate. Held 5 min. at each temperature before reversal	80.0	31.0	78.2	56.3	60.6	98.2
Per cent increase in hardness as compared to original	80.7	0	65.3	5.2	34.4	26.1%

Under the column headed "treatment" it should be noted that the same pieces of each steel were given cumulative treatments. On examination of the data it will be noted that the first submersion treatment gave a hardness value which is almost equivalent to the hardness value obtained after several submersions. With the exception of the manganese steel No. 2, all steels showed an increase in scleroscope hardness which varied from about 5 to 80 per cent.

Changes in Microstructure—The specimens were examined at various intervals of time in order to determine the changes in their microstructures. The photomicrographs are shown in Figs. 32 to 43 inclusive. It will be noted that in every case, with the possible exception of the high manganese steel No. 2 and the nickel steel No. 5, that a typical martensite structure was produced.

Fig. 34 of the cobalt-chromium steel No. 1 shows the microstructure at low magnification 100 X at the extreme edge. It is significant that the structure is mostly austenitic. A similar condition with reference to dark needles in the high nickel steel No. 5 is shown in Fig. 41 which is also at a magnification of 100 X.

The manganese steel No. 2 shows no change in the micro-



Photomicrographs Showing the Decomposition of Austenite in Liquid Oxygen—Steels Nos. 1 and 2. Fig. 32—Steel No. 1 After 12 Hours' Submersion. Scleroscope Reading, Before = 51.4; After = 74.3. Etched with Conc. HCl. Austenite + Martensite + Carbide. 1000 x. Fig. 33—Steel No. 1 After 48 Hours' Resubmersion. Scleroscope Reading, Before = 51.4; After = 79.5. Etched with Conc. HCl. Austenite + Martensite + Carbide. 1000 x. Fig. 34—Steel No. 1 Extreme Edge of Specimen After 72 Hours' Resubmersion; Etched in Conc. HCl. Austenite + Martensite. 100 x. Fig. 35—Steel No. 2 After 12 Hours' Submersion. Scleroscope Reading = 38.0. Deeply Etched with Picric Acid. Austenite. 1000 x.

structure and it is significant that there is no change in the hardness and the specimen remained nonmagnetic. This evidence shows that this austenitic structure is stable at the temperature of liquid oxygen.

It is interesting to note the effect of tempering on the structure produced by the liquid oxygen treatment in the carbon-chromium steel No. 3. The photomicrograph is shown in Fig. 39 and represents the structure produced by tempering 4 days at 374 degrees Fahr. (190 degrees Cent.). A general darkening and tempering of the needles will be noted.

In nickel steel No. 5 it is probable that the dark needles were produced by recrystallization which was accompanied by an immediate change to troostite which would be etched below the surface of the austenite. Fig. 40.

The increase in the hardness of the carbon steel No. 6 is quite significant. The original quenched structure contained a considerable amount of austenite and is shown in Fig. 97 while the structure after 48 hours which appears to be wholly martensite is shown in Fig. 43.

Changes in Specific Gravity—The specific gravity determinations throughout this research were made on pieces weighing about 10 grams. In preparing the specimens for this determination care was taken to clean the surfaces in alcohol so that oil films would be avoided. The specimens were suspended in distilled water by a fine platinum wire and weighed with an analytical balance. The water was maintained at a temperature of 68 degrees Fahr. (20 degrees Cent.) and kept at a constant level.

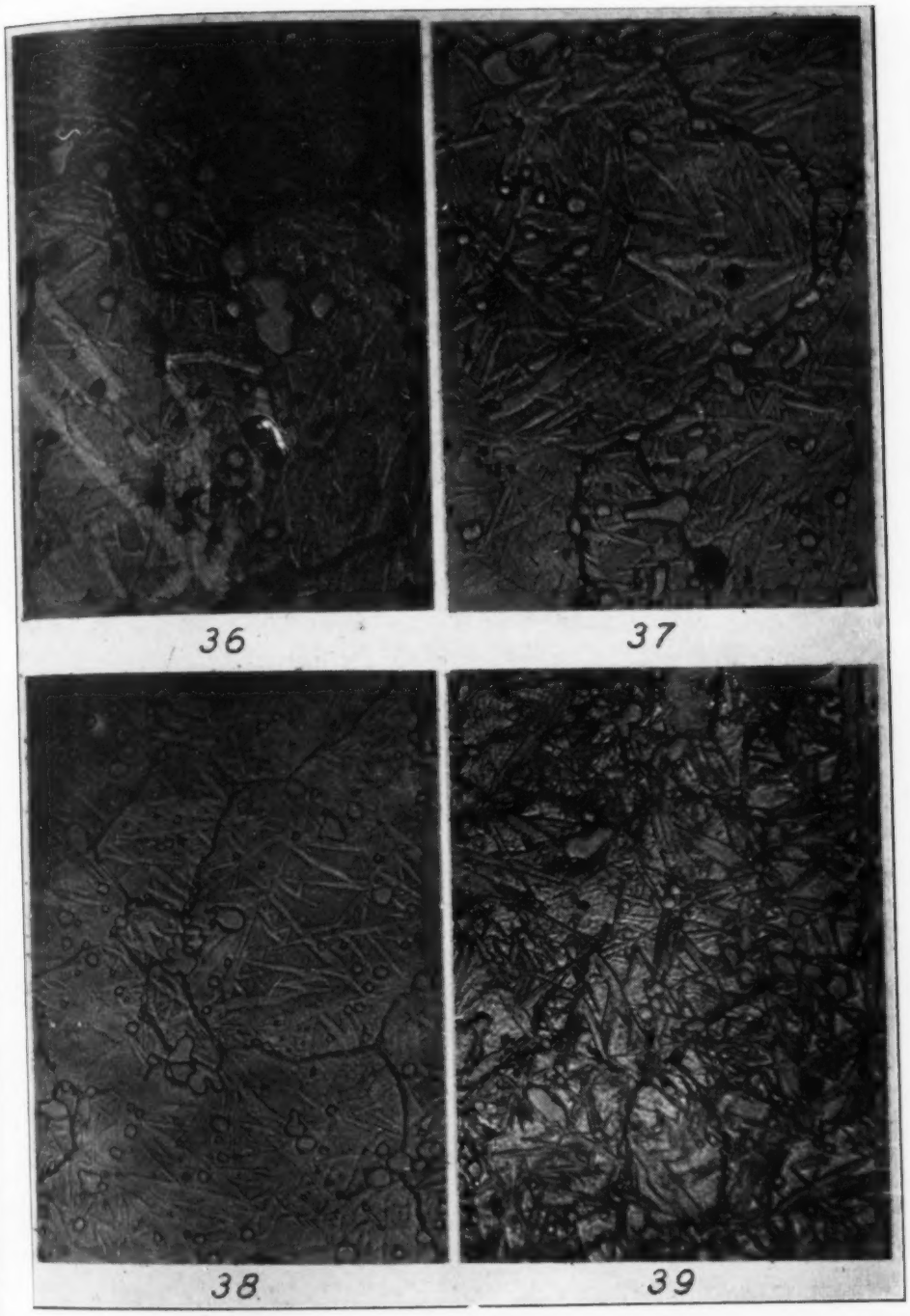
Table V shows the specific gravities before and after the quenched steels Nos. 3, 4, and 6 were submerged in liquid oxygen. Steels Nos. 3 and 6 showed a marked decrease in specific

Table V

Effect of Liquid Oxygen Submersion on the Specific Gravity of Steels Nos. 3, 4, and 6

Steel No.	Quenching Temp. °C.	°F	After Quench S.h.n.	Sp.Gr.	After Submersion S.h.n.	Sp.Gr.
3	1200	2192	47.3	7.9809	78.2	7.8566
4	1250	2282	53.6	8.4641	56.3	8.4524
6	1200	2192	77.9	7.9848	98.2	7.8178

Note: Submersion treatment was the same as the cumulative treatment shown in Table IV. Specimens quenched in 5 per cent NaOH in water at 24 degrees Fahr. (−4 degrees Cent.)



Photomicrographs Showing the Decomposition of Austenite in Liquid Oxygen—Steel No. 3. Fig. 36—Steel No. 3 After 12 Hours' Submersion. Scleroscope Reading, Before = 47.3; After = 76.1. Etched with Conc. HCl. Austenite + Martensite + Carbide. 1000 x. Fig. 37—Steel No. 3 After 48 Hours' Submersion; Scleroscope Reading, After = 74.7. Etched with Conc. HCl. Austenite + Martensite + Carbide. 1000 x. Fig. 38—Steel No. 3 After 3 Hours' Submersion. Scleroscope Reading, Before = 44.9; After = 71.3. Etched with Conc. HCl. Austenite + Martensite + Carbide. 1000 x. Fig. 39—Steel No. 3 Heated 4 Days at 375 Degrees Fahr. After Liquid Oxygen Treatment. Etched with Conc. HCl. Dark Needles. Austenite + Troostite + Carbide. 1000 x.

gravity due to the submersion in liquid oxygen. On the other hand, steel No. 4 showed a slight decrease in gravity. This is in complete agreement with the slight hardness increase of steel No. 4 and the undetectable change in microstructure.

Results of Tests on the Decomposition of Austenite in Liquid Oxygen—The results of the tests on the decomposition of austenite by liquid oxygen submersions seem to warrant the following conclusions.

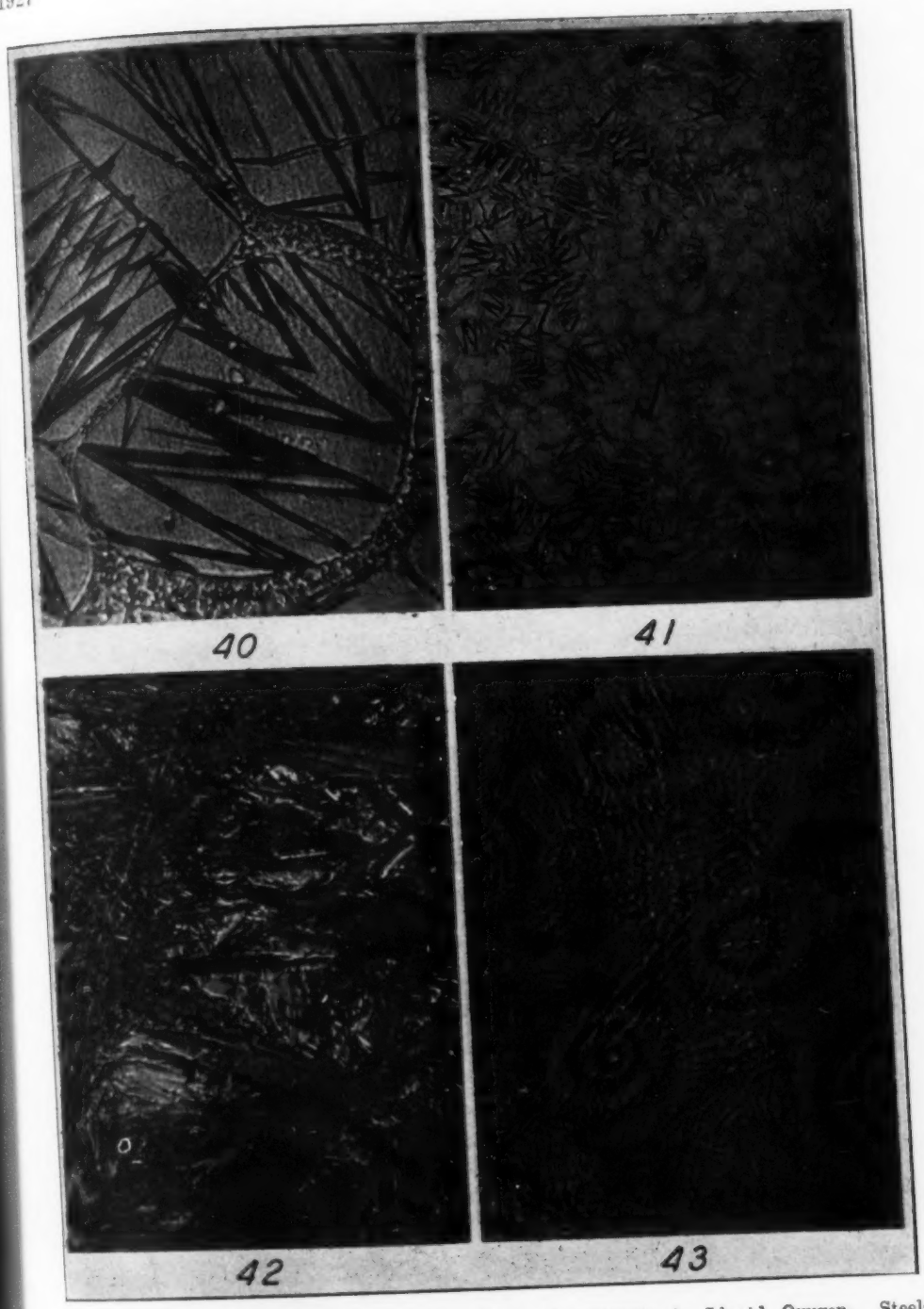
a. The austenitic decomposition of the steels tested is in the following decreasing order for tests on one cubic centimeter specimens quenched in a caustic soda solution and later submerged in liquid oxygen: cobalt-chromium steel No. 1, high carbon-chromium steel No. 3, high nickel steel No. 5, high carbon steel No. 6, and high speed steel No. 4 and high manganese steel No. 2. The manganese and high speed steels, Nos. 2 and 4 respectively, showed no decomposition that could be detected on microscopic examination. There was no increase in hardness of steel No. 2 and only a slight increase in hardness of steel No. 4.

b. The austenitic structures produced in quenched steels have different stabilities and therefore show different amounts of decomposition when subjected to liquid oxygen temperatures. In the plain carbon steel the decomposition goes practically to completion (steel No. 6), while in the case of the manganese and high speed steels there is little or no decomposition.

c. The microstructure produced at liquid oxygen temperatures are similar in appearance to those produced on quenching and include the white needles with the mid-rib structure if the orientation is correct.

d. A greater amount of martensite may be produced at the interior than at the surface. It is believed that this is best explained by assuming a compression on the outside and a tension on the inside in which case the tensional stress favors the formation of the phase of the greater volume and therefore favors the formation of martensite at the liquid oxygen temperature. The austenitic area on the outside of the cobalt-chromium steel No. 1 and the high nickel steel No. 5 are shown in Figs. 34 and 41 respectively.

e. The decomposition of austenite at liquid oxygen temperatures appears to be a recrystallization phenomena which shows



Photomicrographs Showing the Decomposition of Austenite in Liquid Oxygen. Steels Nos. 5 and 6. Fig. 40—Steel No. 5 After 12 Hours' Submersion. Scleroscope Reading, Before = 45.1; After = 56.2. Etched with Picric Acid. Austenite + Carbide + Troostite. 1000 x. Fig. 41—Steel No. 5 Showing Extreme Edge of Specimen After 72 Hours' Submersion. Etched with Picric Acid. Austenite + Carbide + Troostite. 100 x. Fig. 42—Steel No. 6 After 12 Hours' Submersion. Scleroscope Reading, Before = 77.9; After = 95.3. Etched with Picric Acid (Overetched). Austenite + Troostite + Martensite. 1000 x. Fig. 43—Steel No. 6 After 48 Hours' Submersion. Scleroscope Reading, After = 98.3. Etched with Picric Acid. Martensite. 1000 x.

itself first along slip planes and is accompanied by an increase in hardness and a decrease in specific gravity.

f. The formation of martensite from austenite in liquid oxygen probably takes place at a fast rate and almost immediately after submersion as stated by Osmond and Hanemann. However, this rate may be somewhat slower than when it forms on commercial quenching owing to the decrease in the atomic mobility at the much lower temperature. Finally, the reaction does not go to completion, which may be influenced by the greater volume of the martensite which may relieve tensile stress and even produce compressive stress.

g. The decomposition of austenite into martensite does not go to completion in liquid oxygen. The less stable structures as in the carbon steels go more nearly to completion. This is shown by the microstructures after long periods of time and by the changes in hardness.

ON THE TRANSFORMATION OF RETAINED AUSTENITE INTO MARTENSITE BY STRESS

By Kotaro Honda and Keizo Iwase

Abstract

This paper deals with a very interesting fact regarding a quenched structure of alloy steels observed by Dr. J. A. Mathews, which is contradictory to our ordinary belief; the author's experiment confirms E. C. Bain's idea and shows that the phenomenon can be satisfactorily explained by the theory of quenching put forward by one of the authors seven years ago.

THE austenite obtained by quenching steels is unstable at the ordinary temperatures, and consequently shows a tendency to be transformed into the more stable form, that is, into martensite, though at these temperatures the velocity of this transformation is very small. The transformation of the retained austenite into martensite is promoted by several means, such as heating to a high temperature, cooling in liquid air, or repeated mechanical stress, etc.

Recently E. C. Bain[1] put forward the idea that the internal stress set up by cold working in quenched austenite promotes the transformation of the austenite into martensite when the stress exceeds the elastic limit of austenite. His view is based on a few experiments of his own with chromium steel, and also on the following fact found by J. A. Mathews[2]. Contrary to the general belief that, in the quenching of steels, more austenite will be obtained by water quenching than by an oil quenching, Mathews found that in quenching alloy steels more austenite is obtained by oil quenching than by water quenching, provided the other quenching conditions remain the same. Bain's explanation of this fact is as follows: As the thermal stress set up in the specimen is greater in water quenching than in oil quenching, more

[1] E. C. Bain, The Persistence of Austenite at Elevated Temperatures, Transactions, American Society for Steel Treating, Vol. 8, July, 1925, page 14.

[2] J. A. Mathews, Retained Austenite—A Contribution to the Metallurgy of Magnetism. Transactions, American Society for Steel Treating, Vol. 8, November, 1925, page 565. Also *Journal*, Iron and Steel Institute, 1925, No. 2, 299.

A paper presented by proxy at the eighth annual convention of the Society, Chicago, September 20 to 24, 1926. Dr. Kotaro Honda is honorary member of the Society and professor of metallurgy Tohoku Imperial University, Sendai, Japan. Keizo Iwase is assistant professor of metallurgy, Tohuku Imperial University, Sendai, Japan.

austenite is transformed into martensite in water-quenched alloy steels than is the case in oil-quenched steels, and hence less austenite remains in the former case than in the latter.

The present investigation was carried out to confirm Bain's interesting view above referred to.

Transformation of Retained Austenite into Martensite by Cold Working

In order to ascertain the amount of transformation of the retained austenite into martensite, the change of hardness or the intensity of magnetization due to the different degree of cold working in each case was investigated.

A chromium steel containing 1.4 per cent carbon and 5 per cent chromium was used for the specimens. The alloy was melted in a Tammann furnace and cast in an iron mold, 5 millimeters in inner diameter and 15 centimeters in length. The specimens were cylindrical rods 5 millimeters thick and 10 centimeters long. One of them was quenched in oil from 2012 degrees Fahr. (1100 degrees Cent.) and then repeatedly hammered by a 5 kilogram hand hammer, the specimen being prevented from heating by cooling it with water. Then the intensity of magnetization was measured after each hammering. The magnetizing current was 5 amperes.

The following table and Fig. 1 show the results obtained.

Table I

Number of strokes	0	1	2	4	7	10	13	15
Deflection of magnetometer, millimeters	59	93	103	111	126	137	138	142

From Fig. 1 it will be seen that the magnetization increases at first rapidly and then slowly, as the number of strokes increases. After six strokes the magnetization increases to double its initial value. It may be questioned whether this increase of magnetization is not due to the tempering effect caused by the heat of the hammering. To confirm this point, another specimen was again quenched in oil from 2012 degrees Fahr. (1100 degrees Cent.) and then tempered at 100, 200, 300, 400 and 500 degrees Cent. for 20 minutes; the magnetization of the specimen being measured at room temperature after each tempering.

The results of measurement are given in Table II and in Fig. 2.

Table II

Annealing temperature, degrees Cent.	0	100	200	300	400	500
Deflection of magnetometer, millimeters.....	66	67.5	72.5	78.5	94	259

From Fig. 2, we see that even a 20-minute tempering of the specimen below 300 degrees Cent. does not greatly increase the magnetization of the specimen. Hence it may be safely con-

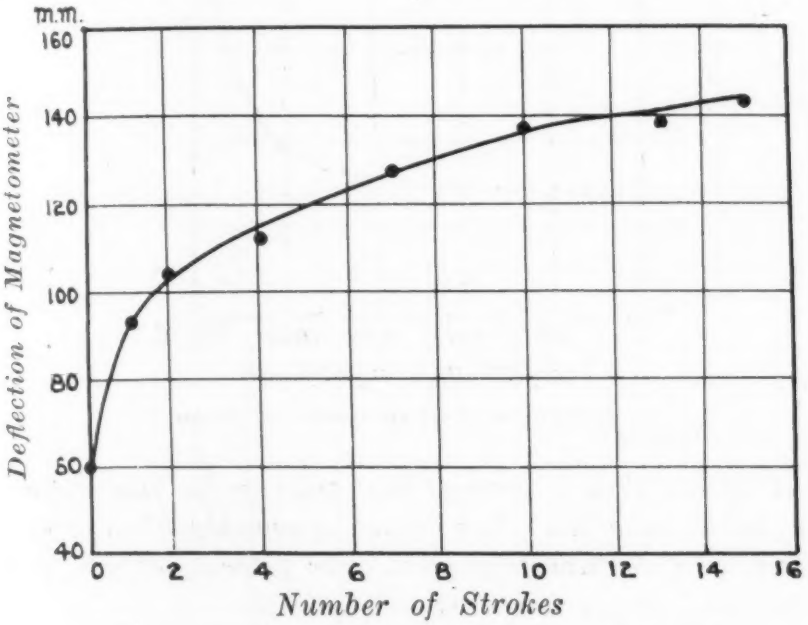


Fig. 1—Intensity of Magnetization of Hammered Specimens.

cluded that if the temperature of the specimen was raised more or less by the hammering, the large increase in the magnetization as shown in Fig. 1 is not due to the tempering effect caused by the heat produced by the hammering, but is to be attributed to the transformation of the retained austenite into martensite. The mechanism by which the hammering accelerates the transformation of austenite into martensite is probably the shock given by the impulse; because this impulsive shock produces a violent atomic agitation in the steel and thus accelerates the said transformation.

Relation Between the Thickness of the Specimen and the Quenched Structure

As the intensity of the internal stress set up in the specimen

during quenching is due to the different rates of cooling in different portions of the specimen, it is to be expected that the greater the thickness of the specimen, the greater will be the resulting internal stress, provided other conditions be the same.

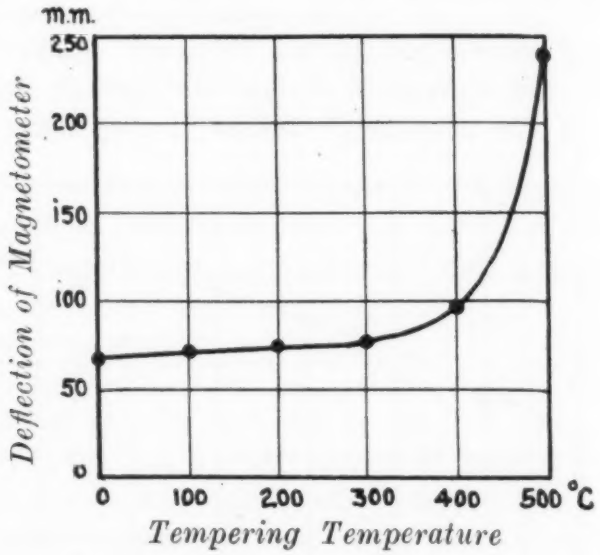


Fig. 2—Intensity of Magnetization of Tempered Specimens.

Hence if Bain's view is correct, the structure of thin specimens will be more austenitic after water quenching than after oil quenching. To confirm this point, the present writers used a chromium steel of the following composition:—

Carbon, Per Cent	Silicon, Per Cent	Manganese, Per Cent	Chromium, Per Cent
0.84	0.20	0.47	2.96

The specimens were made by melting Swedish carbon steel and ferro-chromium, together in a cryptol furnace and the melt was cast into an iron mold 1-inch square in cross-section, and from this, specimens having a thickness of 5, 4, 3, 2 and 1 millimeters, the length and the width of the specimens being respectively 8 and 6 centimeters, were made.

These specimens were annealed at 1562 degrees Fahr. (850 degrees Cent.) for about 1 hour and their hardness was measured with a Rockwell hardness tester. Their hardness numbers were all equal and found to be 25–C.

In comparing the structure of these specimens, their mechanical hardness and magnetic property were measured; if the

quenched specimens contain more martensite, they should be harder and more magnetic. The annealed specimens were heated at 1526 degrees Fahr. (830 degrees Cent.) for 20 minutes and then quenched, in oil or water at room temperature. The Rockwell hardness numbers (C) of these specimens were as follows:

Table III

Treatment	Thickness, Millimeters 5	4	3	2	1
Water quenching	33.6	22.9	18.3	15.7	13.4 (86.6–B)
Oil quenching	23.8	20.2	18.0	16.4	14.4 (87.5–B)
Difference in hardness	9.8	2.7	0.3	–0.7	–1.0

In Table III the numbers given are the mean of 12 values taken at different points in each specimen. The hardness number of the specimen with 1 millimeter thickness was recalculated from

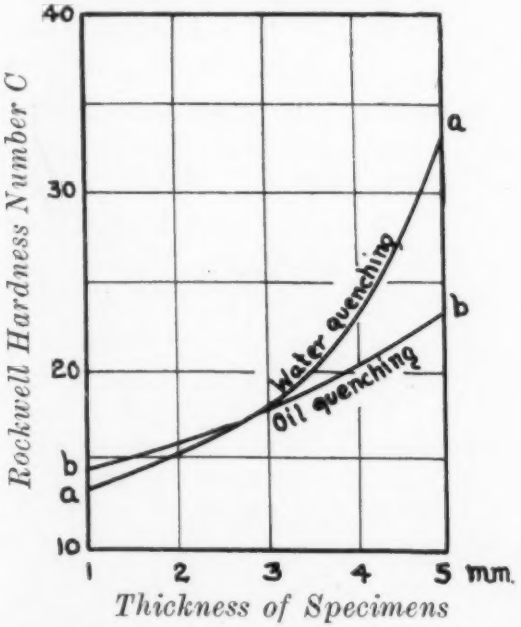


Fig. 3—Hardness of Quenched Specimens.

the number obtained by using the steel ball B, as the diamond cone could not be used for such soft and thin specimens. Fig. 3 shows these results graphically.

From Fig. 3, we see that in the case of both oil and water-quenched specimens, the hardness decreases as the thickness of the specimen decreases, that as regards the thick specimens, water-

quenched ones are harder than the oil-quenched, but as regards the thin specimens, the contrary is the case. As these two curves intersect at point C corresponding to the thickness of 2.7 millimeters, the hardness of the specimens having this thickness are the same, whether they are quenched in oil or in water.

The intensity of magnetization of the above specimens, which have a thickness of 5 and 2 millimeters, was also magneto-metrically measured with the following result:—

Table IV

Thickness	Treatment	Magnetizing Current, Amperes	Deflection of Magnetometer Millimeters
5 millimeters	Water quenching	1	265
5 millimeters	Oil quenching	1	194
2 millimeters	Water quenching	2	353
2 millimeters	Oil quenching	2	372

From these results it may be safely concluded that, in the case of thick specimens, a greater amount of martensite, which is more magnetic, is produced by water quenching than oil quenching, but in the case of thin specimens, the case is just the reverse. Thus Bain's view is confirmed.

Hence the interesting fact observed by Mathews that more austenite is obtained by oil quenching than by water quenching, is the secondary phenomenon associated with intense internal stress (martensitic and thermal stresses), acting impulsively during rapid cooling, when the thickness of the specimen is fairly large.

Experiment With Liquid Air

As the super-cooling of the quenched austenite by liquid air promotes the transformation from austenite to martensite, which is accompanied by an expansion of volume, it is to be concluded that the stress set up in the specimen due to this expansion may possibly prevent a further transformation of the remaining austenite, and that as this stress is small in the case of thin rods, the amount of martensite will be greater in these when immersed in liquid air than in the case of thick rods. The following experiment confirms the above expectation.

Chromium steel containing 5 per cent chromium and 1.4 per cent carbon was made; the three rods, each having a length of

8 centimeters, and diameters of 6, 4 and 2 millimeters respectively, were prepared and subjected to experiments.

At first, these rods were quenched in oil from 2012 degrees Fahr. (1100 degrees Cent.), and after measuring their magnetization, they were cooled in liquid air. Then the magnetization at room temperature was again measured. The following table contains the results of the magnetic observation, the magnetizing current being the same in all cases.

Diameter of rods, millimeters	6	4	2
Deflection before immersing in liquid air, centimeters	18.94	17.60	11.23
Deflection after immersing in liquid air, centimeters	21.77	29.26	34.54
Percentage increase	14.9	60.5	207.5

From the above table, it will be seen that when immersed in liquid air the structure of the quenched steel becomes more martensitic in the case of thin rods than in thick rods; that is, the transformation of retained austenite into martensite is prevented by the internal stress caused by the martensitic expansion during cooling in liquid air.

Summary

1. Quenched austenite can be transformed into martensite by cold working.

2. The internal stress set up in steel by quenching promotes the transformation of retained austenite into martensite, probably by its impulsive action resulting in an atomic agitation.

3. The interesting fact observed by Mathews that in the case of alloy steels, more austenite is obtained by oil quenching than by water quenching, is only valid for thick plates or rods, in which the internal stress caused by rapidly cooling is fairly large, and can be explained as the effect of the stress.

4. By cooling quenched steels in liquid air, the retained austenite is transformed into martensite, the amount of the transformation being less the thicker the specimens.

In conclusion the present writers express their thanks to K. Miyazaki and W. Ota who carried out the measurements.

The Authors

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honorary member of the American Society for Steel Treating. He has, from time to time, made contributions to the Society which have been published in TRANSACTIONS. He was born February 23, 1870, in Yohagi, Japan. In 1897 he graduated from the college of science, department of physics, Tokio University. Mr. Honda became a lecturer in the department of physics of this university, June 1900 and received his doctor's degree in 1902. He was appointed by the

DR. KOTARO HONDA

KEIZO IWASE

minister of education in 1907 as a research fellow abroad and visited Germany, France and England. Upon his return to Japan in 1911, he became professor of physics in Tohoku University, Sendai, Japan. Five years later he received the Academy prize for his investigations of iron and steel. In 1922, Dr. Honda was awarded the Bessemer gold medal by the Iron and Steel Institute of Great Britain and in 1925 he was the recipient of a gold medal from the Japanese Iron and Steel Institute for his investigations pertaining to iron and steel.

KEIZO IWASE was born November 14, 1894, in Kioto, Japan. He graduated from the department of physical chemistry of the College of Science, Kioto Imperial University, in December 1918 and in 1919 he was appointed lecturer in this university. In 1921, he was released from this service and was appointed lecturer in the Tohoku Imperial University, Sendai, Japan. In 1923, he was appointed assistant professor.

Written Discussion: By L. G. Swenson, Western Electric Company, Inc., Chicago.

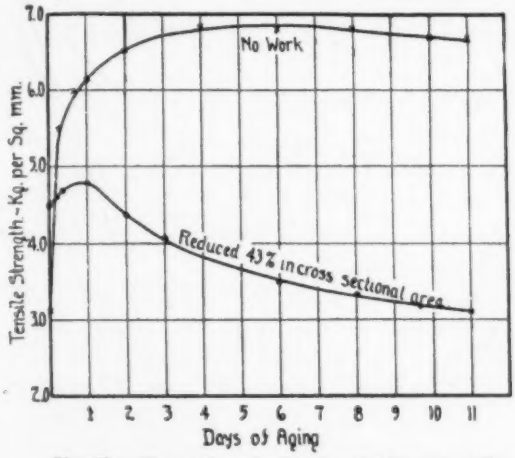
In a paper from this laboratory presented at the February meeting of the American Institute of Mining and Metallurgical Engineers, Dean pointed out that the phenomenon of greater retention of austenite with oil quenching than with the more rapid water quench which had been observed by Mathews, might be considered a special case of a general phenomenon observed in the dispersion hardening of alloys. It had been found, for example, with lead-antimony alloys that practically the same amount of solid solution was retained by a water quench as by an air cool, but that the rate of decomposition of the solid solution was very much greater in the case of the water quench. Hence, if the alloys were examined three days later, the air-cooled alloy will show a considerably greater retained solid solution. In the case of these alloys this can be very readily followed by means of electrical conductivity.

The following table makes this point clear:

BREAKING DOWN OF A 2 PER CENT LEAD-ANTIMONY ALLOY

	Conductivity immediately after quenching	Conductivity three days later
Water Quench	0.353	0.370
Oil Quench	0.354	0.368
Air Cool	0.354	0.364

In the case of steels the process of quenching and aging are so merged that although the solid solution (austenite) retained by water quenching through the critical range may be as great or greater than that retained by oil



Tensile Strength of 2.5% Antimony Alloys Quenched in Water After Annealing at 235 Degrees Cent., Followed by Aging at Room Temperature.

quench, the subsequent decomposition of the water-quenched material is more rapid and hence the total effect of cooling in water is to give more decomposition, that is, less retained austenite.

This, of course, is not an explanation of the Mathews effect but merely an analysis of it in terms of general phenomena of dispersion hardening. We have not explained why rapid cooling increases the rate of decomposition. Mr.

Bain's suggestion of cold work due to drastic quenching may be the answer, but the amount of strain introduced by quenching lead alloys from 235 degrees Cent. is not large. It is certain, however, that cold work does increase the rate of decomposition of supersaturated solid solutions. This is shown in the two accompanying curves for lead-antimony solid solutions, in which the alloys were quenched and one cold-rolled immediately.

It will be noted here that while cold work expedites the breaking down of the solid solution it also introduces over-aging, giving, therefore, much less hardening than an unworked sample. This is pretty good evidence agains the idea that the increased rate of hardening caused by water quenching is due to quenching strain, because a water quenched alloy reaches a definitely higher maximum value of tensile strength than the air cooled alloy, although both started with the same degree of supersaturation.

It, therefore, appears that Mr. Bain's ingenious explanation of the Mathews effect may not be the correct one, and the authors very interesting experiments are merely examples of the general effect of cold work on the rate of decomposition of supersaturated solid solutions.

The more fundamental problem seems to us to be the effect of the rate of cooling on the rate of decomposition of supersaturated solid solutions in general.

In conclusion we wish to compliment the authors in their excellent experimental work and have tried to point out that the theory of quenching strains may not be the whole explanation of Mathews effect, but rather a more general and far reaching relation between the rate of quenching and rate of hardening which was first pointed out by Dean, Zickrick, and Nix.

Written Discussion: By G. R. Brophy, General Electric Company, Schenectady, N. Y.

Table IV shows two magnetizing currents used, the stronger for the smaller specimens and the small current for the large specimens. It seems that the larger specimen would require a heavier current to completely magnetize than the small specimen. This leads to the question whether or not the large specimens were saturated. It is rather difficult to reconcile the magnetic and mechanical hardness shown.

It has been our experience when dealing with small pieces that the lower mechanical hardness was due to loss of heat between furnace and quench. A loss which is not fast enough to cause hardening, but too fast to obtain the full quench. Is it not possible, therefore, that the 2-millimeter samples are troostitic and more magnetic than the 5-millimeter pieces in which a large amount of austenite is retained.

The hardness obtained on chromium steel specimens (shown in Fig. 3) is surprisingly low and the general slope of the curves is contrary to what can be expected when quenching is conducted so that no loss of heat occurs.

The curves submitted with this discussion were obtained on three different steels, one of which is almost a duplicate of Honda's, quenched with no loss of time or heat. The water quenched specimens were all nearly alike in hardness regardless of thickness, while the oil quenched specimens gradually increased in hardness as the size decreased as would be expected.

These pieces were flat stock one-half inch wide by two inches long; the thickness as shown.

With round stock the hardness reading decreased with decreasing

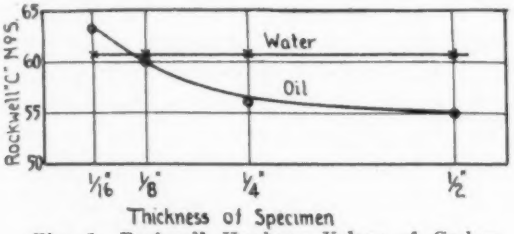


Fig. 1—Rockwell Hardness Values of Carbon Steel. Carbon 1.0%.

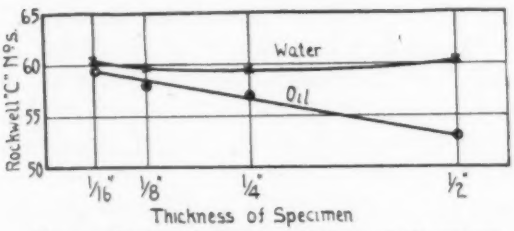


Fig. 2—Rockwell Hardness Values of Chromium Magnet Steel. Carbon 0.80%, Chromium 2.50%, Manganese, 0.50%.

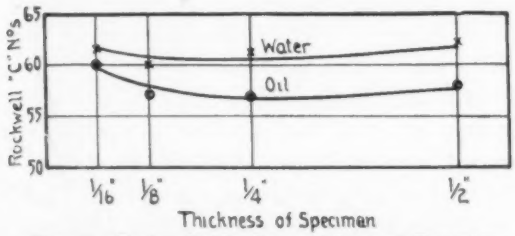


Fig. 3—Rockwell Hardness Values of Tungsten Magnet Steel. Carbon 0.60%, Tungsten 5.00%. All Specimens Quenched from 1470 Degrees Fahr. (800 Degrees Cent.).

diameter when taken on the curved surface. This we attributed to the effect of curvature.

Samples of chromium and tungsten steel were quenched in oil and water from 1050 degrees Cent. and showed Rockwell hardness from 53 C. to 58 C. Upon immersion in liquid air the hardness increase was but a few points and approximately the same for all sizes. Slightly greater for thick chromium quenched in water and for thin chromium quenched in oil.

Microscopical or X-ray evidence should have been presented to show the true structures.

Conclusions 3 and 4 do not agree with the statements made in the paper and may be typographical errors.

Oral Discussion

DR. J. A. MATHEWS: Mr. Chairman, last year I had the pleasure of being at the annual meeting and saying something on the subject of re-

tained austenite, and this paper refers to that work. It is also a pleasure to know that there are three or four papers on the program in which that subject is dealt with.

In the conclusion of my paper last year I stated that it was only preliminary and that applications in various places based upon the conception of retained austenite under various conditions of quenching would be frequent and I invited further work upon the subject and this year's program shows my invitation was accepted.

In this paper of Dr. Honda's there are a few things I would like to have explained. In his Table I, effect of hammering upon hardened chromium steel with the result of converting austenite to martensite, I notice a small test piece five millimeters thick and ten centimeters long, of a very high carbon steel, was used. I should think that hammering a piece of that kind with a ten kilo hammer would result in something like "atomic dispersion" that my friend Archer talks about. I do not see how this hammering was carried out while retaining the piece intact. I would like to know how the experiments were conducted, and whether permanent deformation occurred.

But the most important thing I see that needs attention on page 402. There we have some figures undertaking to show the effect of mass as represented by different thicknesses of test pieces, and if you will note in Table 3, samples of various thicknesses supposed to have been quenched in water and oil show in one case only a hardness higher than the hardness of the annealed material with which he started. There is something very strange about those figures. In fact, it would require a pretty good annealing to get them as soft as the one and two millimeter samples indicate; it would take a rather prolonged and careful annealing to anneal the chrome steel that soft. Those figures are subject to some review. It may be due to typographical errors or something of the kind, because from my experience with steel of the composition quoted, I am very sure that any one of them, from one to five millimeters in thickness, will show practically 60 to 65 Rockwell C-scale, and you would have great trouble in finding the differences in hardness by the Rockwell test with those variations of thickness. I would like to have those matters explained a little more fully by the author.

A. L. DAVIS: I believe that about thirty years ago the results of tests were published (I think in the Transactions of the A. I. M. and M. E.) where steel bars which had been hardened were tested on a tensile machine in the hardened condition, and others hardened at the same time which afterwards had been tapped gently on the end with a hammer were also pulled, and found to be, if my recollection serves me right, about 10 per cent higher in tensile strength. Of course, at the time it was one of those things that no one could understand.

A different illustration of the formation of martensite through mechanical work in austenitic steel, one which I presume Mr. Bain has given, is that of a Hadfield's steel, a 13 per cent manganese steel. We take a piece and run the hack-saw across, and the first cut the saw makes you think you are going to cut it, but after the first cut or two you have produced a surface

glaze, which I take it, is martensitic, and the saw will no longer cut. Indeed, not even a new saw will now cut it.

These two would seem to be illustrations of the subject worth considering.

O. W. ELLIS: There is quite a considerable difference of opinion in regard to the possibility, when quenching brasses containing about 60 per cent copper, of retaining the brass in the condition of pure beta solid solution. In experiments which we carried out at Toronto University when I was there we made a number of tests varying the temperature from which we quenched, the temperature of quenching being within the beta solid solution range, and varying the temperature of the water in which the quenching took place. We found that when we used the highest quenching temperatures and the coldest water, we had the greatest difficulty in preventing alpha from precipitating out from our solid solution, while when we lowered the temperature from which we quenched and raised the temperature of our water, we seemed always to be able to get our beta held in perfect solid solution, that is, there was no precipitation of alpha. I mention these things because they seem to be in line with the remarks that were made by the speaker before the last, and while there certainly needs to be considerable more work done along this line to make definite the conditions under which one can obtain pure beta and cannot obtain pure beta, there seems to be fairly sound evidence to bear out the statements which I have made.

A. V. DEFOREST: In reference to the discussion by Mr. Swenson, I would like to suggest that he has brought out several possibilities. We usually think of cold work as being a mechanism which is introducing energy into the material and is therefore proceeding from a more stable to a less stable system.

On the other hand, it is perfectly possible that a certain amount of mechanical energy may go into a system and act in exactly the opposite way. It is easily conceivable that in a system which is not in equilibrium a slight amount of mechanical energy can help the system in the direction of greater stability rather than less, exactly as a pile of sand may seek its position of repose more readily if it is on a base which can be vibrated a little. I imagine that perhaps some precipitation which takes place and which is assisted by cold work may be a step from a position of less stability towards a position of more stability, in which the cold work is just a slight mechanism for increasing the degree of freedom.

Of course, there is another explanation possible, especially in regard to Mr. Bain's work, that a certain amount of mechanical energy will change the austenite to a material which has a greater degree of freedom than the austenite itself by the introduction of mechanical energy, and that that, in turn, seeks its equilibrium in the form of martensite, so that actually the cold work does precipitate out the martensite, even though it introduces energy of its own, again making for an end product which is more stable than the original.

Authors' Written Closure

The present authors should like to express their best thanks to these

gentlemen, who were so kind to take part in the discussion of the subject connected with the change of retained austenite into martensite by stress.

As regards L. G. Swenson's remarks, it will be noticed that the cause of the hardening in the lead-antimony alloy quoted by him is an aging effect, but not an immediate effect as in our case, and that it does not correspond to the case of steel; that is, in the former case, the change is the precipitation of antimony from a lead-rich solution, which takes place very slowly with time, while in the latter case, the change of retained austenite into martensite is an allotropic change taking place very rapidly during quenching. The aging effect of the lead-antimony alloy corresponds to the change of martensite into troostite in the case of steel taking place very slowly at low temperature.

According to the view of the present writers, the aging effect of the lead-antimony alloy is due to the precipitation of the new crystals on the grain boundaries of the solid solution and the subsequent growth of these crystals, with the lapse of time. The appearance of the minute crystals on the grain boundaries causes the hardening of the alloy (slip-interference theory) and their growth results in a softening of it, just as in the case of the recrystallization of cold-worked metals. Thus during aging at room temperature, the hardness or tensile strength first increases, attains a maximum and then decreases.

In the case of steel, martensite is the hardest structure and the austenite the softest one, and hence the change of retained austenite into martensite is always accompanied by an increase in hardness. As the further change of martensite into troostite involves a diffusion of carbon atoms and hence can hardly take place at room temperature owing to the great viscosity of the metal, even with an application of stress, as was already confirmed microscopically; while the change from austenite into martensite consists of the change of configuration of iron atoms from gamma to alpha type, which can be effected by a small relative motion among neighboring atoms, and hence can take place at a very low temperature by the action of a mechanical stress. Hence in the case of steel, any appreciable softening cannot take place at room temperature, as it does in the case of lead-antimony alloys.

Thus the age-hardening of the lead-antimony alloy and the change of retained austenite into martensite are completely different phenomena. The above explanations will probably serve to solve these questions raised by Mr. Swenson.

Mr. G. R. Brophy asked whether the thick specimens were magnetized to saturation or not. It is obvious that even the thin specimens, the magnetization is far from saturation; for our object of investigation it is not necessary to have the saturation magnetization. It will be sufficient to compare their magnetization for the specimens of the same dimensions under the same strength of the magnetizing field, both for water and oil quenchings. Thus the comparison should be made between two 5-millimeter specimens or two 2-millimeter specimens, but not between 5 and 2-millimeter specimens.

(*Continued on Page 473*)

FATIGUE STRENGTH OF HARD STEELS AND THEIR RELATION TO TENSILE STRENGTH

By J. M. Lessells

Abstract

This paper gives some data on the tensile and fatigue properties of very hard steels. In connection with the former test an application of fine extensometers to the measurement of elastic properties is made. The fatigue of such hard material is also discussed and curves shown in the paper.

The relationship between the tensile strength, Brinell hardness and endurance limit is discussed and it is shown how residual stresses present in the material may influence such a relationship.

The superiority of medium carbon steel in gear application is shown by the results obtained.

Introduction

IT is now well known that the tensile test does not give complete information on the characteristics of material subjected to alternating stresses and when such conditions exist it is also necessary to obtain fatigue values of the material if safe and economical working stresses are to be the result. While the above statement should be taken as a general rule it should be pointed out that fatigue tests require a large number of test bars and a relatively long time for testing. It may therefore be impracticable in all cases to obtain such fatigue data and the question of the relation of such to the tensile test values is of great practical importance.

With a view to giving more data on the fatigue of very hard steels while discussing further the relationship which these have to the tensile test the present paper is presented.

Tensile Strength and Brinell Hardness

Before we come to a discussion of fatigue tests it may be of interest to consider the relation between the tensile strength and hardness number, the latter being obtained by the Brinell test. It is now generally accepted[1] that the relationship between such hard-

[1] R. H. Greaves and J. A. Jones: Ratio of Tensile Strength of Steel to Brinell Hardness *Journal*, Iron and Steel Institute, 1926.

A paper presented before the eighth annual convention of the Society, Chicago, September 20 to 24, 1926. The author, J. M. Lessells, is in charge of the Mechanics Section of the Research department of the Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.

ness and tensile strength is fairly constant for steels which have a hardness number less than, say 300. In order to illustrate this point the author has plotted in Fig. 1 values of tensile strength and hardness number for a series of steels taken from the Report of the Institution of Automobile Engineers[2]. It will be seen from

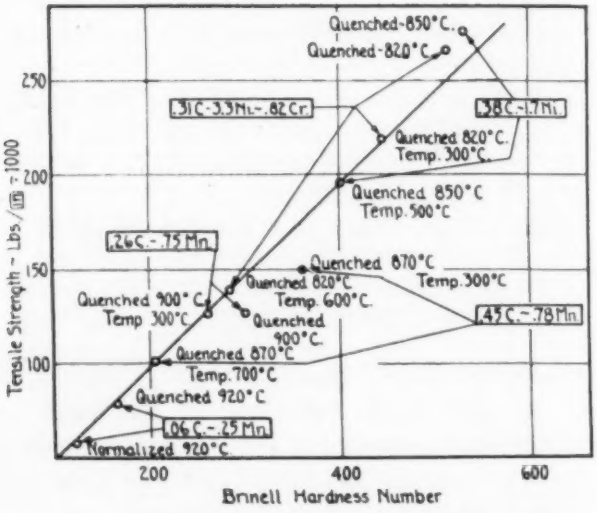


Fig. 1—Tensile Strength—Brinell Hardness Relationship for Miscellaneous Steels.

this that the relation is fairly constant which may be expressed by the equation P = 486 H, where P is the tensile strength in pounds per square inch and H is the Brinell hardness number. Examining Fig. 1 it will be seen that this relationship only appears to hold for steels in well tempered conditions and the author feels that, while this is difficult to explain, any departure from such may be caused by residual stresses present in the steel. For instance, the values for the 0.1 per cent carbon, a steel not affected by heat treatment, are on the straight line, whereas those for the 1.50 per cent nickel, and 3 per cent nickel—0.8 per cent chromium are above the line for the condition as quenched but again fall on it when tempered. The values for the 0.20 per cent carbon and 0.35 per cent carbon steels are below the line for the condition as quenched and again fall on the line when tempered. These results made the writer feel the advisability of examining the values obtained by other investigators and in Figs. 2 and 3 are similar curves for a 3.5 per cent nickel

[2]Report of Steel Research Committee; Institution of Automobile Engineers (1920).

steel[3] and a 4½ per cent nickel—1½ per cent chromium plotted from data given by Gough[4]. These figures contain corresponding data on the endurance limit values which will be referred to later. In these cases also it may be observed that the relationship between

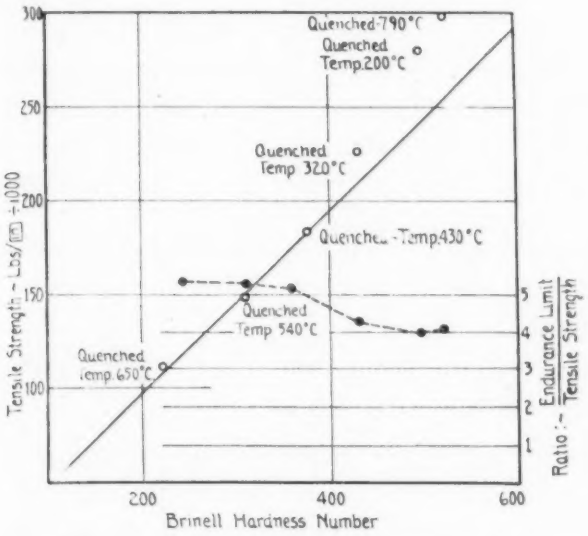


Fig. 2—Tensile Strength—Brinell Hardness Data for 3.50 Per Cent Nickel Steel (Moore and Jasper).

tensile strength and hardness number is good when the steels have been sufficiently tempered but give high values of hardness when this is above 400, approximately.

Tensile Strength: Brinell Hardness and Fatigue

The above results led the writer to carry out certain tensile and fatigue tests on very hard steels to see if further light could be thrown on this subject. For this purpose two steels were chosen—a 0.42 per cent carbon and a 1.0 per cent carbon. These were taken in bar form 1.25 inches diameter, cut into test bar lengths, and roughly machined into tensile and fatigue test bars. They were then heat treated and ground to finished dimensions. The treatment given was as stated below, the 0.42 per cent carbon steel being designated as steel "A" and the high carbon as steel "B".

[3]In a recent paper by W. Rosenhain, R. G. Batson and N. P. Tucker, entitled, "Effect of Mass in Heat Treatment of Nickel Steel"; Iron and Steel Institute, 1926. The values of tensile strength for the hard condition are below those given by the straight line relationship. This might mean that the values obtained by Gough and Moore, which are above those for straight line relation, may be explained on the basis of ball deformation.

[4]Fatigue of Metals; by H. T. Gough; Scott Greenwood, 1924, Steels No. 55 and No. 70, pp. 285 and 286.

Steel A—Treatment No. 1.

Normalized 1580 degrees Fahr., quenched in salt solution X at 1562 degrees Fahr. and drawn at 210 degrees Fahr. for one hour.

Steel A—Treatment No. 2.

Normalized 1580 degrees Fahr., quenched in salt solution Y at 1435 degrees Fahr. and drawn at 590 degrees Fahr. for ½ hour.

Steel B—Treatment No. 1.

Normalized at 1520 degrees Fahr., quenched in lime salt solution at 1472 degrees Fahr. and drawn at 570 degrees Fahr.

For each of these conditions tensile and fatigue tests were made.

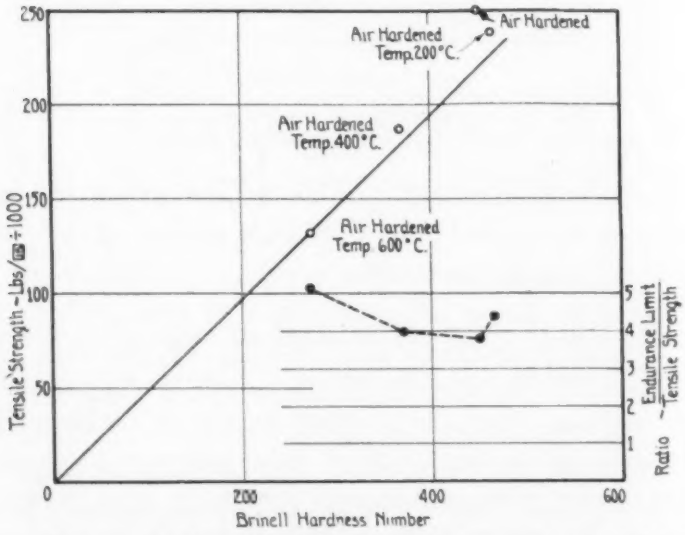


Fig. 3—Tensile Strength—Brinell Hardness Data for Nickel Chromium Steel of the Composition of 0.31 Per Cent Carbon, 4.30 Per Cent Nickel, 1.47 Per Cent Chromium (Gough).

In these tests considerable difficulty was experienced. Using the standard A. S. T. M. test bar, fracture took place in the grips and it was necessary to re-design the test bar so that the ends were 1 inch diameter, while the central portion was 0.505 inch diameter with a 2-inch gage length, adequate fillets being provided. In this manner the effect of stress concentration was removed and satisfactory tests were obtained, fracture taking place usually at the

middle of bar. For the determination of the proportional limit a Marten's mirror extensometer was used, thereby enabling great accuracy to be obtained. In Fig. 4 a curve for the elastic stage of tensile test of high carbon steel is shown. The Brinell hardness tests were made on the ends of the tensile test bars, using specially hard balls.

In the fatigue tests the cantilever form of test bar was employed. Considerable difficulty was again experienced in order to get satisfactory results and the diameter of the small tapered end of the test bar had to be increased. In Fig. 5, a fatigue test

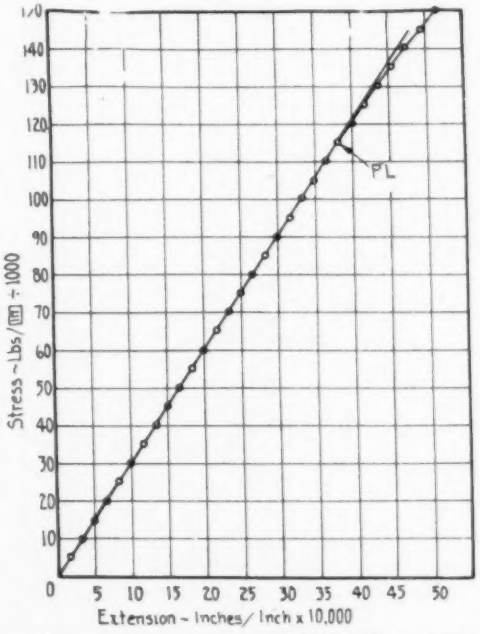


Fig. 4—Elastic Stage of High Carbon Steel.

curve for the high carbon steel is shown. Similar curves were obtained for the other steel but these are not shown. Tables I and II give the complete data for all the tests made.

Table I
Tensile Test Results

Steel	Treatment	Prop. Limit lbs/sq. in.	Ult. Stress lbs/sq. in.	Elong. on 2" %	Red. of area %	Brin. No.
A	1	31,000	212,000	2.0	5.5	578
A	1	40,000	249,000	1.6	4.7	578
A	2	35,000	215,000	7.0	41.6	477
A	2	.....	215,000	6.7	32.8	477
B	1	122,000	240,000	3.7	9.3	495
B	1	118,000	242,000	8.5	13.0	495

Residual Stress Tests

The tensile and hardness values as obtained on these steels were plotted as previously explained and are shown in Fig. 6. The divergence from the straight line relation for Steel A-1 is very apparent while A-2 is in better agreement and B-1 in good agreement with the law.

These results led to making some measurements[5] in order to determine if residual stresses were present. Pieces of the same steel 4 inches long and 1.25 inches diameter were ground all over and heat treated in a similar manner to the previous test bars.

Table II
Fatigue Test Results

Steel	Treatment	Endurance Limit lbs/sq. in. for complete stress reversal.
A	1	81,000
A	2	98,000
B	1	112,000

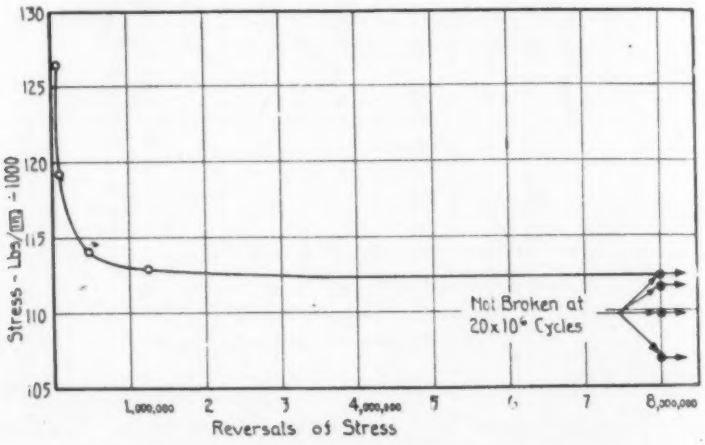


Fig. 5—Fatigue Test Curve of High Carbon Steel.

By successive measurement of length and removal of surface layers it was established that the following compressive residual stresses were present in the outside.

Steel	Residual Stress
A-1	110,000 pounds per square inch
A-2	30,000 pounds per square inch
B-1	0 pounds per square inch

From these measurements the full line part *ab* of the curve of

[5]In this work the writer was assisted by J. P. Denhartog of the Mechanics Section.

Fig. 7 was drawn and on the basis that the tensile and compressive stresses were in equilibrium the dotted part of the curve *bc* was completed, giving a general picture of stress distribution.

It is not contended that these residual stress values are any more than an indication of what is present in the material and that they are strictly comparable with the discrepancy shown by the previous straight line law. It is quite appreciated that the test

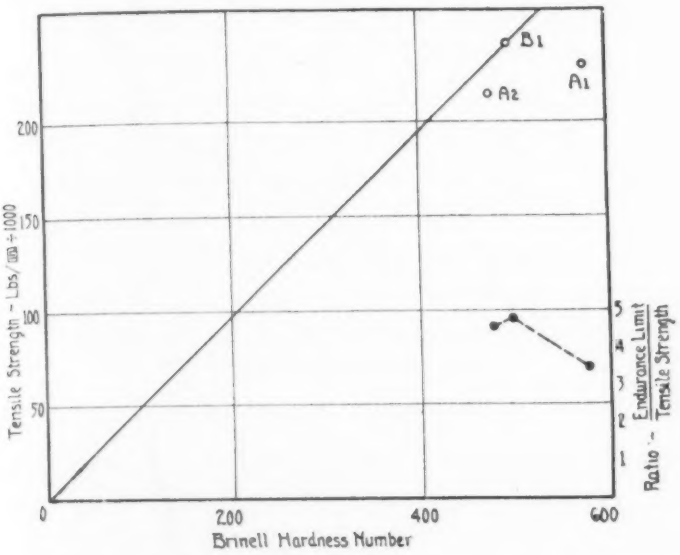


Fig. 6—Tensile Strength—Brineli Hardness Data for Carbon Steels (W. E. M. Co.).

bar form itself will have an influence on these results. They do confirm, however, that when such departure is obtained residual stresses are present.

Discussion of Results

Referring to Figs. 2, 3 and 6 it will be observed that these include at the right hand side, values of the ratio of endurance limit to tensile strength. Examining these more closely it will be observed that if there is departure from the straight line law for hardness and tensile strength there are also low values for this ratio. If residual stresses are present such a reduction in endurance limit values is what would be expected. The author nevertheless admits some difficulty in explaining the reason why any residual stress affects the Brinell hardness number. It can be concluded, however, that there is some danger in interpreting

fatigue values of such steels from tensile and hardness test data.[6]

A further point brought out by these results is that steel A-2 possesses a very high endurance limit value and at the same time high ductility. This is a steel used by the R. D. Nuttall Company for their gears and enables the employment of high working stresses without failure by fatigue coupled with the additional factor, due

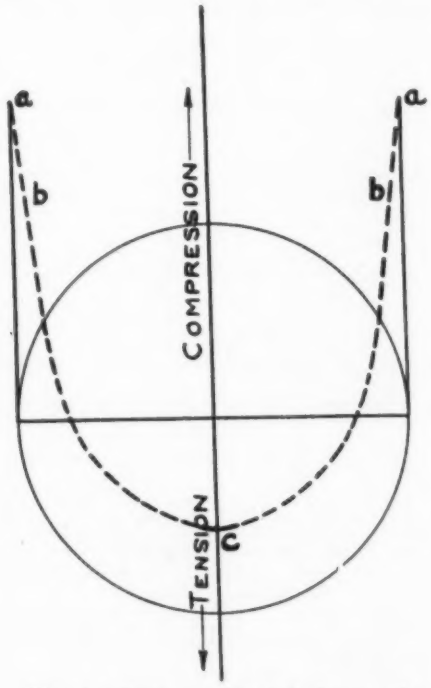


Fig. 7—Curve of Residual Stress Distribution.

to the ductility, of being able to accommodate itself to the stress concentration encountered in such work and which has recently been fully discussed.[7]

Conclusions

In general we are justified in assuming that there will be a strict comparison between tensile strength and Brinell hardness number provided we have a homogeneous material. Any departure from homogeneity will show a difference because the tensile test is an average for the complete section while the hardness test is a

[6]Some indication of this was given previously by the author. Transactions, American Society for Steel Treating, 1922.

[7]See paper by S. Timoshenko and R. V. Baud on Gear Tooth Stresses before the American Gear Manufacturers' Association, Detroit, May 13, 1926.

surface test only. It seems therefore that this relation between tensile strength and hardness number is a linear one and that non-homogeneity as may be caused by residual stresses gives departure from the law.

This departure from the straight line relationship for the tests made by the author is associated with a decrease both in tensile strength and in the ratio of endurance limit to tensile strength. This can be explained on the basis of there being residual stresses present, and while the data of Gough shows an increase in tensile strength and a reduction in endurance ratio making it necessary to do further work on the subject, possibly sufficient has been said to show that caution is necessary in trying to estimate endurance limit values from tensile strength or Brinell test data, for steels which have a Brinell hardness of 350 or over.

It is also shown that a medium carbon steel when specially treated gives fatigue test results which when coupled with the high ductility as found are vastly superior to high carbon steel for gear application.

Acknowledgements

Acknowledgement is made to the Westinghouse Electric and Manufacturing Company for permission to publish these results and to T. F. Hengstenberg, laboratorian, for carrying out the tensile and fatigue tests.

DISCUSSION

Written Discussion: By D. J. McAdam, Jr., U. S. Naval Engineering Experiment Station, Annapolis, Maryland.

Mr. Lessell's paper contains valuable information of the endurance properties of hard steels.

The importance of avoiding stress concentration in such steels is brought out by Mr. Lessells' description on page 416 of his tension test specimen, which had to be designed specially for this work.

Avoidance of stress-concentration in endurance specimens is even more important than in tension test specimens. Unfortunately Mr. Lessells does not describe the form of the test specimen that he used. He merely refers to it as of the cantilever type. If he used the Woehler cylindrical form, maximum stress would be at a fillet. Such concentration of stress at a fillet would be especially harmful in hard material. Mr. Lessells refers to a "small tapered end" that had to be redesigned. So the specimen that he used was probably not of the Woehler form. It is very desirable, however, that the specimen used in his endurance tests be carefully described so as to give an idea of the stress distribution in the specimen and the position of fatigue fracture.

The author reaches the conclusion that the Brinell hardness should be

proportional to the tensile strength throughout the entire range of hardness, if initial stress be absent. In the hardest steels, however, initial stress is probably never absent. It is probable, moreover, that initial stresses in hard steels influence the tensile strength as well as the Brinell hardness. So it appears doubtful whether departure from a linear relationship between tensile strength and Brinell hardness in hard steels should be attributed entirely to internal stress.

In a paper published about two years ago in TRANSACTIONS,[1] Dr. S. L. Hoyt described Meyer's investigation of the ball indentation hardness test. Meyer's work showed that the relationship between load and depression could be expressed by an equation in which there are two constants "a" and "n". The constant "a" is closely related to yield point and "n" represents the rate at which the metal hardens with cold working. This equation is based on measurements made after maintaining the load until equilibrium has been reached.

In a recent paper by the writer[2], the values for "a" and "n" were plotted against "percentage increase in tensile strength due to cold working." The graphs thus obtained show that "a" increases and "n" decreases with increase in tensile strength due to cold working. The Brinell test, therefore, which measures a combination of two different properties, and in which the load is maintained for an arbitrarily selected time, could hardly be expected to give values exactly proportional to the tensile strength throughout the entire range of hardness, whether the range of hardness be due to cold working, chemical composition or heat treatment.

Written Discussion: By H. F. Moore, University of Illinois, in charge, Investigation of the Fatigue of Metals.

Test data are very few for the fatigue strength of quenched and drawn high-carbon steels, and Mr. Lessells' paper gives a welcome addition to the data already available. Gillett and Mack[3] have pointed out that the ratio of endurance limit to tensile strength falls off for steel having a Brinell number above about 400, and Mr. Lessells' paper pushes this limit of 400 down to a somewhat lower value.

Mr. Lessells' study of internal stress in steel is of great interest. Certainly when initial stresses of the order of 100,000 pounds per square inch are found in steel, internal stress must be considered a factor in fatigue strength, —or in any other kind of strength.

Written Discussion: By J. F. Harper, Allis-Chalmers Manufacturing Company, West Allis, Wisconsin.

Mr. Lessells' paper has been one of great interest and in confirmation of his relation between tensile strength and Brinell hardness number, we wish to present the attached chart for his information.

Curve No. 1 is taken from "The Making, Shaping and Treating of Steel", by J. M. Camp and C. B. Francis.

[1] S. L. Hoyt, "The Ball Indentation Hardness Test," TRANSACTIONS, American Society for Steel Treating, September, 1924.

[2] D. J. McAdam, Jr., "Effect of Cold Working on Endurance and Other Properties of Metals," TRANSACTIONS, American Society for Steel Treating, December, 1925.

[3] "Notes on Some Endurance Tests of Metals," *Proceedings*, A. S. T. M., Vol. 24, Part II, p. 476, 1924.

Curve No. 2 is taken from data collected at the Allis Chalmers Manufacturing Company from twenty-five different materials which had over eighty different heat treatments.

We agree with Mr. Lessells that the deviation from the line shown by

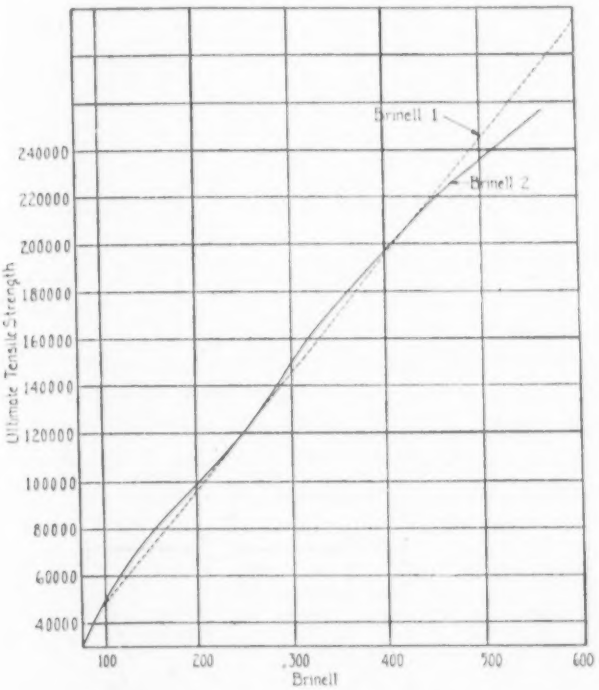


Fig. 8—Curves Showing a Comparison of Ultimate Tensile Strength and Brinell Hardness Numbers. Curve No. 1 Taken from J. M. Camp and C. B. Francis Book Entitled "Making, Shaping and Treating of Steel. Curve No. 2 Results of Tests Made at the Allis-Chalmers Manufacturing Company, West Allis, Wis.

Camp and Francis to be due to residual stress and to variations in grain size effecting the Brinell reading.

Curve No. 2 must be disregarded above about 425 Brinell hardness because of the compression of the ball.

Author's Closure

Referring to the points raised by Dr. McAdam the Woehler cantilever form of test piece was used in the fatigue tests. The original form is as shown in Fig. 9 and due to breakage which took place at the small end of the taper adjoining the shoulder for the ball bearing the form was modified to the one shown in Fig. 10.

This prevented fracture at the small end. The forms were essentially the same as those designed by Dr. McAdam and previously described by him.[1] Fracture always occurred at points removed from the fillets. The author is not just clear what Dr. McAdam means by initial stress. If he means residual stress then the effect of this on the relation between tensile strength and hardness has been discussed. The author does not know whether this stress affects

the Brinell hardness or the tensile strength. If it can be shown that certain steels such as the 3.50 per cent nickel, the results of which are shown in Fig.

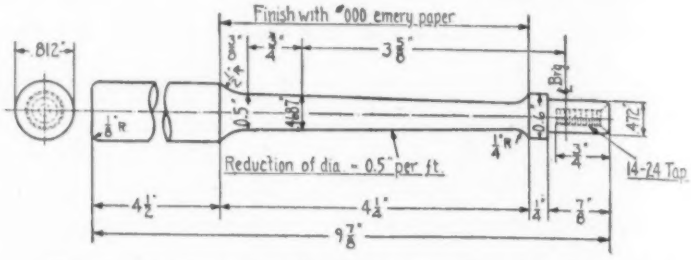


Fig. 9—Sketch of Cantilever Test Bar Used in Some of the Earlier Tests.

2 have a tensile instead of a compressive stress on the outside then this will indicate that the residual stress has an effect on the hardness determination. Data are lacking however on this point.

The author thanks Professor Moore for his comments on the paper. It appears that the limit set by Gillett and Mack will have to be reduced as indicated.

The additions of J. F. Harper are welcome. The author notes that he agrees with the idea expressed in the paper that residual strees upsets the

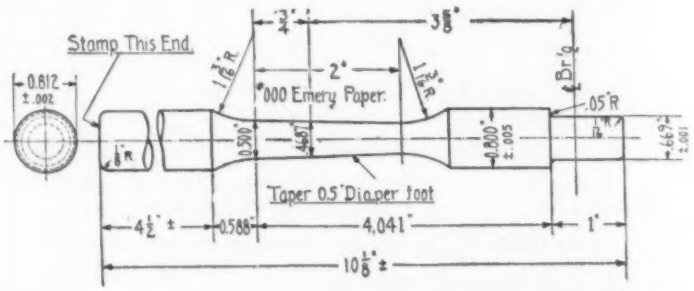


Fig. 10—Modified Form of Cantilever Test Bar Used in Tests Described.

relation between tensile strength and Brinell hardness. It might be mentioned here that the hardness tests described in this paper were made with specially hard balls so deviation could not be explained on the basis of flattening of the ball.

In conclusion the author states once more that further work may have to be done on this subject using in addition other methods of hardness determination. The main idea in the paper was to advocate caution in applying the relations which exist between tensile strength, Brinell hardness and endurance limit for constructional steels to all kinds of hard steels.

[1]D. J. McAdam, Jr., *Chemical and Metallurgical Engineering*, December 14, 1921; and *Mechanical Engineering*, July, 1925.

STUDIES ON ELECTRIC WELDING

By Ludwig J. Weber

Abstract

The effect of various gases on the metal deposited in electric welding as well as the effect of the arc on the gases has been studied. The experiments show that abnormal carburizing steels were produced when the steel was deposited in an atmosphere of carbon dioxide, carbon monoxide, nitrogen and air while normal carburizing steel was produced when the weld was made in an atmosphere of helium.

Analyses of the gases show that the carbon dioxide was decomposed into carbon monoxide and oxygen. The oxygen caused the oxidation of some of the iron.

Carbon monoxide decomposed with the formation of carbon dioxide. There was a great increase in nitrogen, which was obtained by difference, which could be best explained by assuming the formation of a carbonyl which does not condense at ordinary temperatures and which is not absorbed in the reagents used for gas analysis.

The nitrogen combines with the iron to form the nitride, part of which is retained in the deposited metal and part of which is condensed on the sides of the container. The analyses of the deposit suggested the formula Fe_5N_2.

No gas analyses were made for the welds made in helium and in air.

Introduction

A survey of the present practice in commercial electric welding and the results obtained indicated the importance of a metallographic study of the entire process and the important factors involved. The investigation as planned covers four main headings as follows:

1. Effect of atmosphere; including tests in air, nitrogen, carbon dioxide, carbon monoxide, and helium.

2. Effects of fluxes which includes a variety of fluxes with a view to protection of the deposited metal and the welding rod from the oxygen and nitrogen in the air, and the removal of ob-

A paper presented before the eighth annual convention of the Society, Chicago, September 20 to 24, 1926. The author, L. J. Weber, is instructor in metallography, University of Minnesota, Minneapolis, Minn.

jectionable impurities from the deposited metal while in the molten condition.

3. Effect of using various alloys as filling rod in the welding operation.

4. The effect of using alloy steel welding rods.

Scope of the Present Paper. The present paper is intended to be a preliminary report but covers the first part of the investigation, that is, the effect of the various atmospheres on electric welding.

Results of Investigation

Effect of Air. The results of the investigation to date show that when welds are made in air the deposited metal contains oxides which appear as slag, and nitrides which appear as needles after annealing. Both of these products can be identified microscopically. Their effects have been studied by means of carburizing tests and they have been found to produce what is known as "abnormal steels." It appears, however, that they are better described as "abnormal carburizing steels."

Effect of Nitrogen. In the case of the experiment carried out in nitrogen, it has been found that the nitride forms in the deposited metal as shown by the microscopic examination. In addition, there is a volatile material deposited on the walls of the containing vessel which chemical analysis indicates is the nitride Fe_5N_2.

Effect of Carbon Monoxide. Carbon monoxide was found to form an equilibrium with carbon and carbon dioxide so that there was some oxidation by the carbon dioxide. In addition there was formed a volatile compound of iron which deposited on the walls of the containing vessel. Chemical analysis of this volatile material showed it contained approximately 50 per cent iron and suggested the compound iron dicarbonyl of the formula $Fe(CO)_2$. The gas analyses showed an increase in the unabsorbed gas which is usually designated as nitrogen, but the increases observed could not have been due to increase in concentration of nitrogen. The formation of iron carbonyls which do not condense and which are not absorbed by the reagents used in gas analysis seems to be the most likely explanation. Such compounds, however, have not been identified in this work. There was not sufficient carburizing of the

deposited material to make it detectable by means of microscopic examination.

Effect of Carbon Dioxide. In the case of carbon dioxide, oxidation was more pronounced and carbon monoxide was formed. There was again observed a volatile iron compound which condensed on the sides of the vessel and an increase in the amount of the unabsorbed gas.

Effect of Helium. In the experiments with helium, the first metal deposited showed the presence of nitride needles in the annealed specimen but the last metal deposited appeared to be practicallly free from nitrides and gave normal structure on carburizing. The helium was known to contain about 6 per cent nitrogen and the experiments suggest that the nitrogen is rapidly taken up by the iron to form the nitride. In order to purify the helium in later experiments, magnesium was heated in the commercial gas by means of the electric current. The magnesium combined with the nitrogen to form the nitride and left pure helium. Welds made in helium purified in this way gave a normal structure on carburizing.

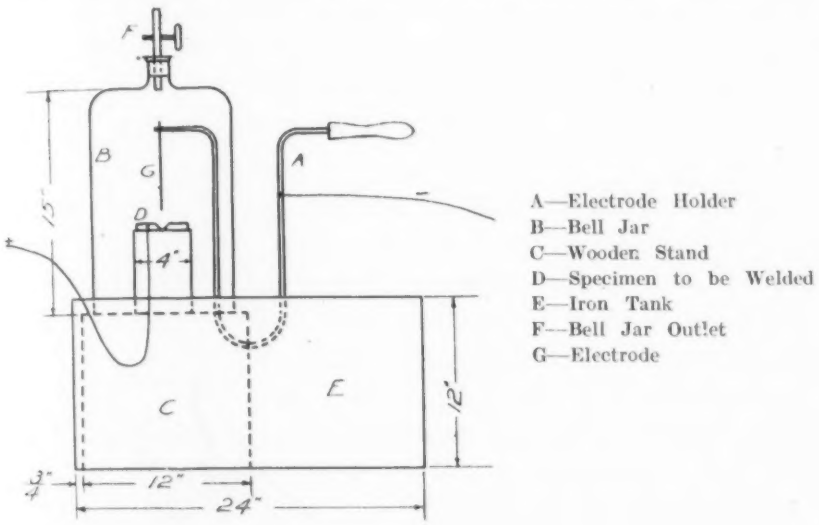


Fig. 1—Diagrammatic Sketch of the Apparatus Used in These Experiments.

Apparatus and Methods of Testing

In order to carry out electric welding tests in an atmosphere of known composition it was necessary to design and construct special apparatus for that purpose. A sketch of the apparatus used in this investigation is shown in Fig. 1.

A wooden stand (C) was made to fit an iron tank (E) which held the water that acted as a seal for the gas. A hole was sawed into the top of the stand and a block about six inches high was built on the projection to support the specimen to be welded. A glass jar (B) having an outlet (F) on top was then set on the stand so as to enclose the specimen (D) to be welded. The water level was about one inch above the bottom of the jar on the outside and about five inches on the inside after the gas had been put into the jar.

The electrode holder (A) consisted of a three-eighths inch diameter brass rod bent into the shape shown in the drawing. A wooden handle was put on the one end which served as an insulator and at the same time made it possible to manipulate the welding rod conveniently. The entire holder was wound with rubber tape and then given three coats of varnish in order to prevent any leakage of the current through the water. The copper leads and the welding rod were fastened to the holder by means of set screws. By this arrangement the welding rod could be inserted or taken out of the jar easily without admitting air.

The specimen to be welded (D) was bolted on to a well-insulated copper cable and was made the positive pole. It consisted of boiler plate about ½ inch thick, 4 inches long and 1 inch wide into which a 90 degree V-shaped groove had been cut with a milling cutter.

The electric current was obtained from a motor generator. The current used during welding varied from 60-80 volts and from 100-150 amperes.

In filling the container with the desired gas, the specimen was first clamped in position. The air was then pumped out by means of a vacuum pump which filled the container with water. The gas was then put into the container either through the outlet on top or else through the bottom by the downward displacement of the water.

The expansion of the gas in the jar due to the heat given off by the arc was quite large and the welding had to be interrupted frequently in order to permit the gas to cool. If this were not done, the pressure would finally become so great that the gas would be lost from the container. This made it impossible to make good welds but gave the effects of the gases on the deposited metal as

well as the effect of the arc on the gases, both of which were desired.

In analyzing the gases both before and after welding, the sample was obtained by connecting the outlet with an Orsat apparatus using ordinary precautions not to admit any air with the gas. The gas was analyzed for carbon dioxide, oxygen, and carbon monoxide by absorption in potassium hydroxide, pyrogallol, and acid cuprous chloride, respectively. Check analyses were made on each sample. The unabsorbed gas was not further analyzed due to the fact that proper apparatus was not available. In most cases it would be nitrogen, although there is a possibility of some other gas being formed during the welding, which would not be removed by the above reagents and thus be reported as nitrogen.

Welding In A Carbon Dioxide Atmosphere

The carbon dioxide was obtained from a cylinder of commercial gas and had the following analysis:

	per cent
Carbon dioxide (CO_2)	97.5
Oxygen (O_2)	0.5
Carbon monoxide (CO)	0
Nitrogen (N_2), by difference	2.0

After the welding tests the gas had the following analysis:

	per cent
Carbon dioxide (CO_2)	86.4
Oxygen (O_2)	0.6
Carbon monoxide (CO)	8.3
Nitrogen (N_2), by difference	4.7

The arc was easier to maintain in this atmosphere than in the case of welding in air. After welding, the sides of the jar were covered with a brownish black soot which was magnetic and dissolved in hydrochloric acid. This deposit was not further analyzed but was probably similar to that described later under the tests in carbon monoxide.

The decomposition of the carbon dioxide may be expressed by the following equation:

$$2CO_2 \rightarrow 2CO + O_2$$

This should give an increase in oxygen equal to one-half of the increase in carbon monoxide. The analyses, however, show

that the oxygen content remained about the same. After welding, the water was covered with a film of red oxide which indicated that the liberated oxygen combined with the iron to form the oxide and thus did not show an increase on analysis as should have been the case according to the above equation. The complete reaction may be indicated by the following equation:

$$3CO_2 + 2Fe \rightarrow 3CO + Fe_2O_3$$

Fig. 2 shows the structure of the steel as deposited in welding. Irregular patches of pearlite can be seen while the round black particles are slag or blowholes. The groundmass is ferrite.

Fig. 3 shows the same specimen as Fig. 2 after carburizing in a well known commercial carburizing compound for six hours at 1650 degrees Fahr. and then cooling in the furnace in the carburizing box as recommended in the McQuaid-Ehn test. The structure can be seen to consist of very coarse lamellar pearlite with excess of both cementite and ferrite. It may be noted that all slag particles or blowholes are on the boundary of the cementite or entirely surrounded by it. This condition was found throughout the specimen.

The results show that oxidation of the iron occurs while welding in a carbon dioxide atmosphere with the formation of carbon monoxide gas. If we compare the gas analysis with that obtained while welding in a carbon monoxide atmosphere, it is noticed that in both cases the nitrogen obtained by difference increases more than should be due to experimental error. The probable cause for this increase is given in the discussion of the results obtained in a carbon monoxide atmosphere. The reason the increase in nitrogen is less in the case of carbon dioxide atmosphere is most likely that the concentration of the carbon monoxide was much lower, and therefore less of the iron-carbon monoxide compound would be formed.

Again, if we compare the photomicrographs, Figs. 3 and 6 of the deposited material after carburizing, we note that both of them show an abnormal carburizing steel. In the case of the material deposited in the carbon dioxide atmosphere there is still a tendency to form lamellar pearlite, while in the case of the material deposited in the carbon monoxide atmosphere there is no indication of any lamellar pearlite. This may again be explained by assum-

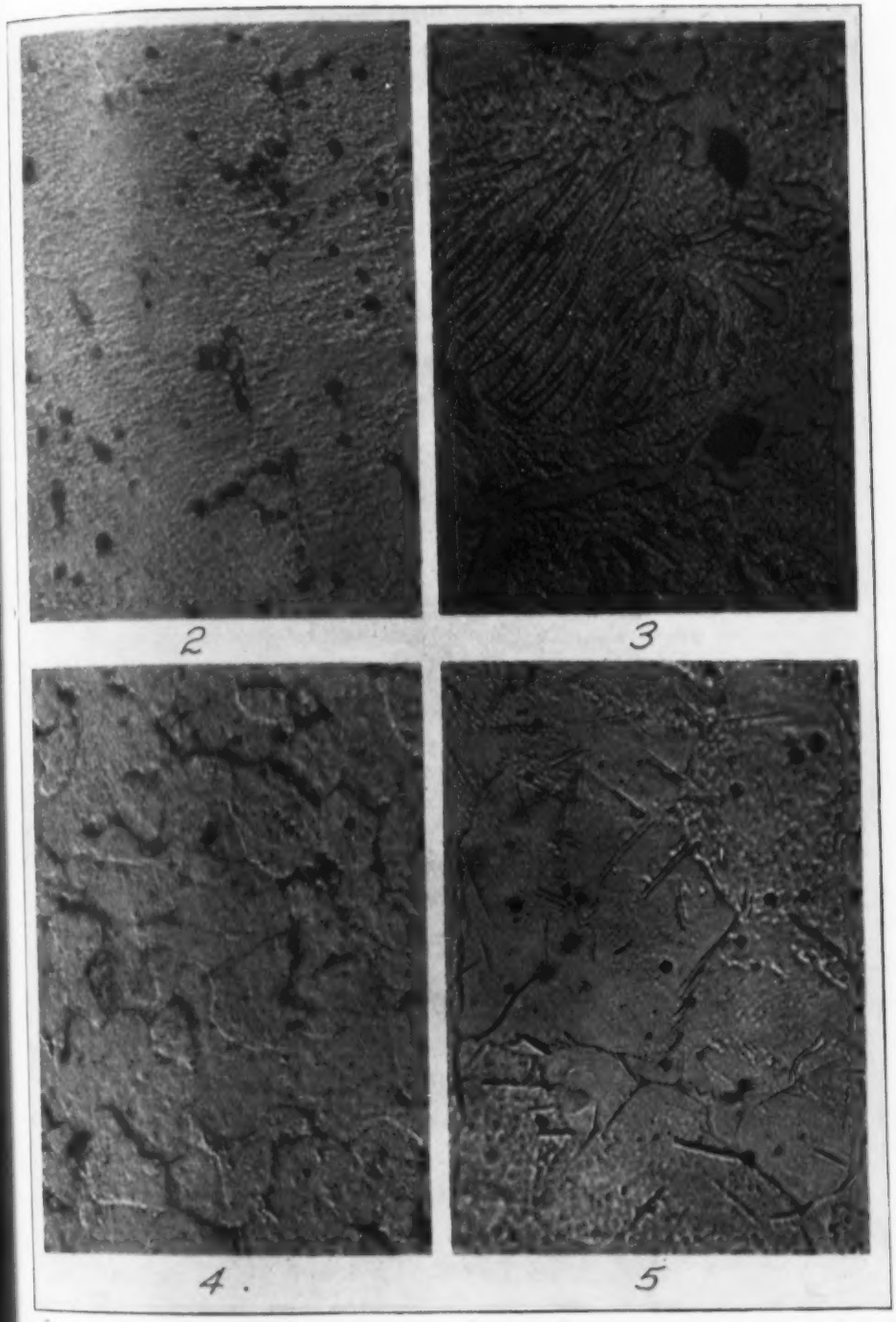


Fig. 2—Photomicrographs Showing the Structure of the Steel as Deposited in Welding. The Irregular Patches are Pearlite and the Rounded Black Particles are Slag or Blowholes. The Groundmass is Ferrite. Specimen Etched with Picric Acid. Mag. 1000X. Fig. 3—Photomicrograph Showing the Same Specimen as in Fig. 2—After Carburizing for Six Hours at 1650 Degrees Fahr., as Recommended in the McQuaid-Ehn Test. Specimen Etched with Picric Acid. Mag. 1000X. Fig. 4—Photomicrograph of the Metal Deposited in a Carbon Monoxide Atmosphere. The Dark, Irregular Areas are a Mixture of Ferrite and Cementite. The Rounded Black Spots are Either Slag or Blowholes. Specimen Etched with Picric Acid. Mag. 1000X. Fig. 5—Photomicrograph Showing the Structure Obtained on Heating Specimen of Fig. 4—at 1650 Degrees Fahr. for Fifteen Minutes, Cooling in the Furnace. The Carbides are Seen in the Form of Needles and Not as Pearlite. Specimen Etched with Picric Acid. Mag. 1000X.

ing that the concentration of the substance causing this abnormal carburizing was greater in the material deposited in the carbon monoxide than in that which was deposited in a carbon dioxide atmosphere.

Welding In Carbon Monoxide Atmosphere

Carbon monoxide was prepared by allowing formic acid to drop into a flask containing concentrated sulphuric acid. The gas generated was passed through a solution of potassium hydroxide to absorb any carbon dioxide that might have been formed and then was collected in the bell jar by downward displacement of the water.

The analysis of the original gas was as follows:

	per cent
Carbon dioxide (CO_2)	0.2
Oxygen (O_2)	0.2
Carbon monoxide (CO)	98.2
Nitrogen (N_2), by difference	1.4

After welding the anaylsis of the gas was:

	per cent
Carbon dioxide (CO_2)	3.8
Oxygen (O_2)	0.4
Carbon monoxide (CO)	90.0
Nitrogen (N_2), by difference	5.8

The arc could be maintained more readily than in the case where carbon dioxide atmosphere was used but not as easily as with the nitrogen atmosphere. The jar was covered with a brownish soot similar to that obtained when welding in carbon dioxide only in greater quantities.

The gas analysis indicates that carbon monoxide is not stable during the welding process. Due to the fact that some of the iron is at such a high temperature, the following reactions may occur:

$$6Fe + 2CO \rightarrow 2Fe_3C + O_2.$$
$$CO + O_2 \rightarrow 2CO_2.$$
$$\left\{ \begin{array}{l} Fe + O_2 \rightarrow FeO \\ 3Fe + 2O_2 \rightarrow Fe_3O_4 \end{array} \right\}$$

The per cent of unabsorbed gas which is reported as nitrogen increased to a greater extent than could have been due to concentration of nitrogen. This increase could not be attributed to experimental error because the analyses were checked with good

agreement. It appears that these results are best explained by assuming the formation of iron carbonyls which do not condense and which are not absorbed by the reagents used in gas analysis. The presence of these compounds, however, has not been definitely established.

The soot on the sides of the container was analyzed and contained 51.9 per cent iron. A black material similar to graphite separated out when the substance was digested with 1:1 hydrochloric acid. This analysis suggests the formulae $Fe(CO)_2$ which contains 50 per cent iron.

Fig. 4 shows the microstructure of the metal deposited in the carbon monoxide atmosphere. The dark irregular areas are a mixture of ferrite and cementite. The round black spots are due either to blowholes or slag particles. No increase in carbon content could be noticed on microscopic examination.

Fig. 5 shows the structure obtained on heating the material deposited in welding at 1650 degrees Fahr. for fifteen minutes and then cooling in the furnace. The carbide can be seen to be in the form of needles and not as pearlite which would be the structure ordinarily obtained from this heat treatment.

Fig. 6 shows the structure after carburizing the material according to the McQuaid-Ehn test. The photomicrograph shows only areas of cementite and ferrite with no pearlitic structure. It may be noted that nearly all the slag or blowholes are enclosed in the cementite areas. This structure is similar to that of Figs. 3 and 9.

The results show that oxidation and carburization of the iron may occur while welding in a carbon monoxide atmosphere. The gas analysis indicates that some gaseous compound is formed which is not absorbed by the reagents used in the ordinary gas analysis. This would, of course, increase the apparent per cent of nitrogen which was obtained by difference. This large increase in nitrogen could not be explained satisfactorily in any other way.

The material deposited in the carbon monoxide atmosphere contains some substance which has a great effect on the way in which the carbide separates from the austenite or solid solution. On annealing even a low carbon steel, the carbide will not separate out in a pearlitic structure but as carbide needles, which indicates that this substance is active in preventing the formation of lamellar pearlite. After carburizing, this great effect on the precipitation

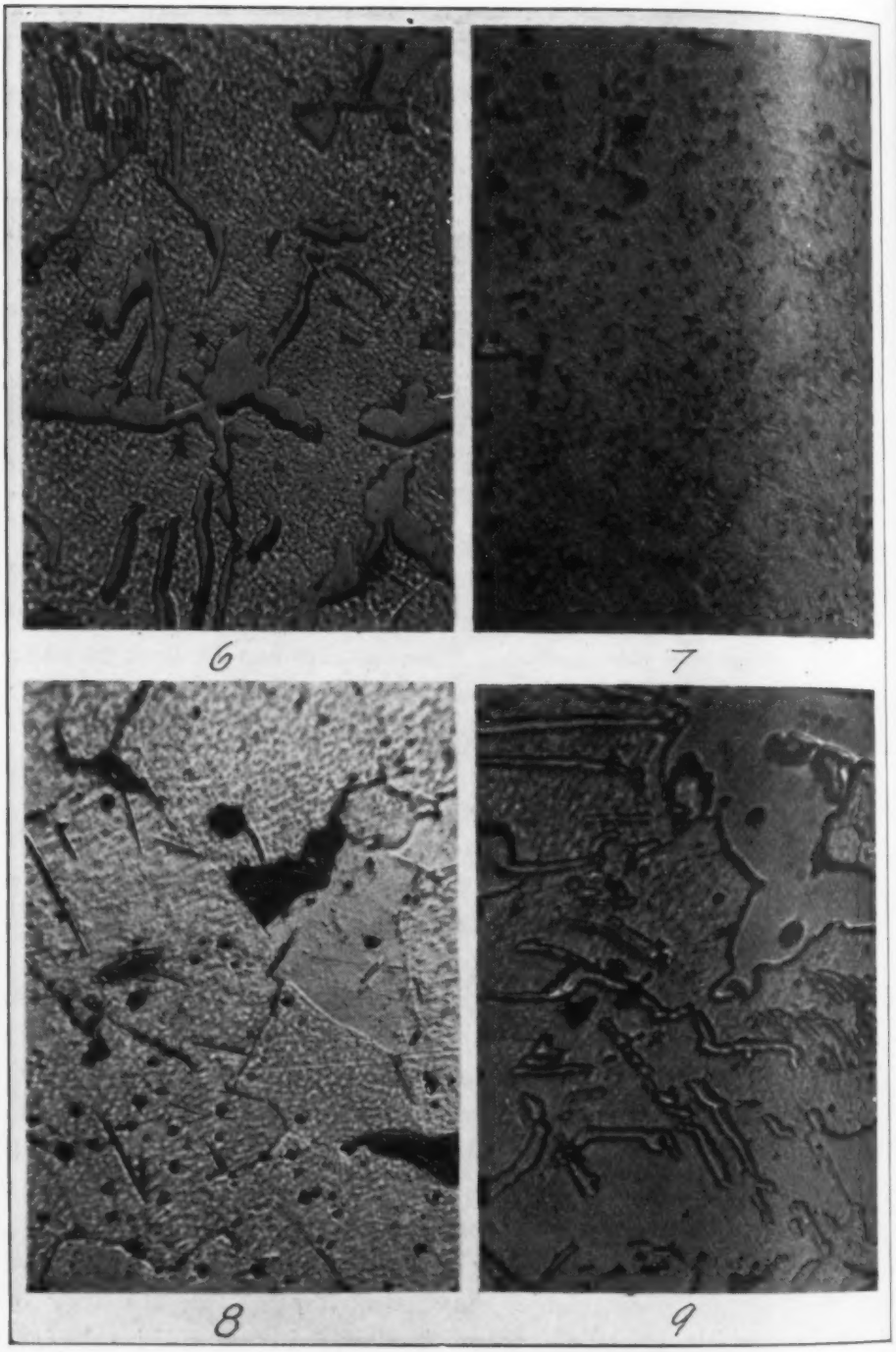


Fig. 6—Photomicrograph Showing the Structure of Specimen Same as Fig. 5—After Carburizing According to the McQuaid-Ehn Test. Specimen Etched with Picric Acid. Mag. 1000X. Fig. 7—Photomicrograph Showing the Structure of the Metal Deposited in an Atmosphere of Nitrogen. The Cementite or Nitride Particles Can be Seen Distributed Throughout the Piece. Specimen Etched with Picric Acid. Mag. 1000X. Fig. 8—Photomicrograph Showing the Structure Obtained by Heating a Specimen After Welding to 1650 Degrees Fahr., Holding for Fifteen Minutes and Then Slowly Cooling. The Pearlitic Areas and Nitride Needles Can be Easily Distinguished. Specimen Etched with Picric Acid. Mag. 1000X. Fig. 9—Photomicrograph Showing the Structure of a Specimen Similar to Fig. 8—After Carburizing According to the McQuaid-Ehn Test. Specimen Etched with Picric Acid. Mag. 1000X.

of the carbide still remains as no pearlite is present in the carburized piece, the structure of which consists of cementite and ferrite.

The analysis of the material on the sides of the jar indicates that a compound $Fe(CO)_2$ might have been formed. This compound has not yet been reported in the literature and further work would have to be done in order to substantiate this conclusion.

Welding In A Nitrogen Atmosphere

The nitrogen was obtained from a cylinder of commercial gas and had the following analysis:

	per cent
Carbon dioxide (CO_2)	0
Oxygen (O_2)	0.6
Carbon monoxide (CO)	0
Nitrogen (N_2), by difference	99.4

After the welding tests the gas had the following composition:

	per cent
Carbon dioxide (CO_2)	0.4
Oxygen (O_2)	0.1
Carbon monoxide (CO)	0
Nitrogen (N_2), by difference	99.5

The arc could be maintained much more readily than in the case when carbon monoxide or carbon dioxide atmospheres were used. A soot covered the sides of the jar the same as when carbon monoxide or carbon dioxide was used but on rough estimation there was a heavier deposit in the case of the nitrogen atmosphere. An analysis of this soot showed that it contained 90.3 per cent iron. It was not analyzed for any other elements due to the small amount of sample that was available. The iron content, however, suggests the compound Fe_5N_2 which contains 90.9 per cent iron and has been reported in the literature.

The gas analyses show that some of the carbon in the steel was oxidized to carbon dioxide while a small amount of the oxygen most likely combined with the iron to form the oxide.

Fig. 7 shows the structure of the deposited metal. The cementite or nitride particles can be seen distributed throughout the piece. The small round particles may be slag or blowholes. In most cases they were found, by careful focusing, to be holes.

Fig. 8 shows the structure obtained by heating the specimen after welding to 1650 degrees Fahr., holding for fifteen minutes

and then cooling slowly. The pearlite areas and the nitride needles can be readily distinguished. The nitride, similar to cementite, is not attacked by picric acid. The nitride, however, is found as needles in areas of ferrite whereas the cementite generally collects in areas of pearlite. As yet no suitable etching reagent is known to distinguish between needles of these microconstituents.

Fig. 9 shows the structure in the material after carburizing according to the McQuaid-Ehn test as previously described. The structure shows small areas of pearlite and excess of ferrite and cementite. The characteristic nitride needles cannot be seen in this photomicrograph which may be due to the fact that the nitrides coagulated on long heating and in the presence of large amounts of carbide to form wider bands of nitrides which cannot be distinguished from the cementite. The structure is similar to that of Figs. 3 and 6.

The results from these experiments show that the iron combines quite readily with nitrogen at the temperature of the electric arc. In the low carbon steels, the nitride appears as needles in the ferrite, similar to results obtained by other investigators. The nitride seems to have great effect on the way in which the carbide will precipitate out. In low carbon steels it does not prevent the formation of pearlite, but in high carbon steels obtained by carburizing, it causes the cementite to precipitate in large masses instead of in the pearlitic structure. The amount of oxide present was so small that it would hardly affect the precipitation of the cementite, so the action may be considered to be due to the nitride present in the steel.

The material did not give as abnormal a structure as that deposited in carbon monoxide atmosphere, but more abnormal than that deposited in carbon dioxide as can be seen by comparing with Figs. 3 and 6. This would indicate that the effect of the nitride on the precipitation of the cementite was not as great as that due to the substance formed while welding in a carbon monoxide atmosphere.

Welding In Air

In making welds in air it was impossible to enclose the specimen in the glass jar and then make the weld as was done in the previous experiments. This was due to the fact that the iron would combine rapidly with the oxygen present which would cause

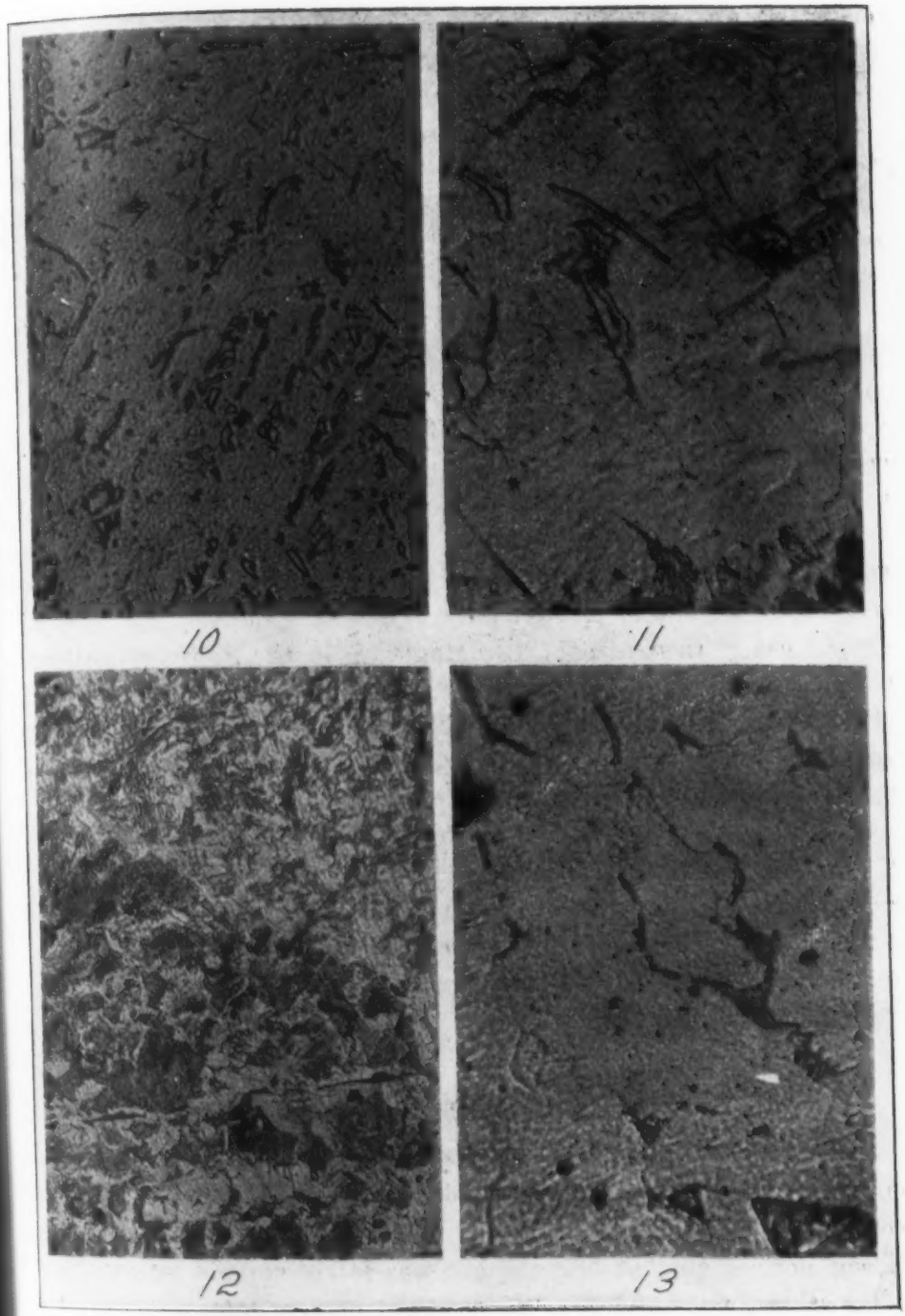


Fig. 10—Photomicrograph Showing the Structure of Deposited Metal When Welding in an Atmosphere of Air. Fig. 11—Photomicrograph Showing the Structure of the Deposited Material After Heating to 1650 Degrees Fahr. for Thirty Minutes and Then Slowly Cooling. Specimen Etched with Picric Acid. Mag. 1000X. Fig. 12—Photomicrograph Showing the Structure of Deposited Material in an Atmosphere of Air After Being Carburized According to the McQuaid-Ehn Test. Specimen Etched with Picric Acid. Mag. 100X. Fig. 13—Photomicrograph Showing the Structure of the Material Deposited in an Atmosphere of Helium. Specimen Etched with Picric Acid. Mag. 1000X.

the water to rise in the container and finally cover the specimen to be welded. The weld was made by using commercial welding apparatus and ⅛-inch rod containing below 0.1 per cent carbon.

The structure of the deposited material is shown in Fig. 10. It can be seen to consist of material etching similar to cementite distributed as small particles throughout the ferrite. The small round particles may be slag or blowholes. In most cases they were found to be slag inclusions.

Fig. 11 shows the structure of the material deposited after holding at 1650 degrees Fahr. for thirty minutes and then cooling slowly. The portion on top of the photomicrograph is part of the test specimen that was welded. The structure in the weld can be seen to consist of cementite, pearlite, and nitride needles similar to those obtained when welding in a nitrogen atmosphere.

Fig. 12 shows the structure in the deposited metal and the specimen welded after carburizing according to the McQuaid-Ehn test. The boundary between the weld and the specimen welded can be easily recognized. The structure in the deposited material shows large globules of cementite with hardly any pearlite, which structure is characterisitic of abnormal carburizing steels. The specimen welded shows a normal structure as can be seen from the structure in the right of the photomicrograph.

The cause of the abnormal carburizing might be due to either the oxides or the nitrides present in the steel. From previous experiments, it has been shown that nitrides cause abnormal carburizing steels. The effect of oxygen alone, present in the steel as oxides or as a gas, on the carburizing properties of the steel has as yet not been determined.

Welding In Helium Atmosphere

The helium was obtained from the Bureau of Mines and, according to their analysis, contained about 6 per cent nitrogen, the remainder being helium. In making the welds in this atmosphere, it was noticed that at first the arc was fairly easy to maintain but after several rods had been deposited it became more difficult. On examining the material deposited it was noticed that the first part of the weld gave very abnormal structure on carburizing while the last portion deposited gave a more nearly normal structure but still was not entirely normal. This suggested that the nitrogen in the

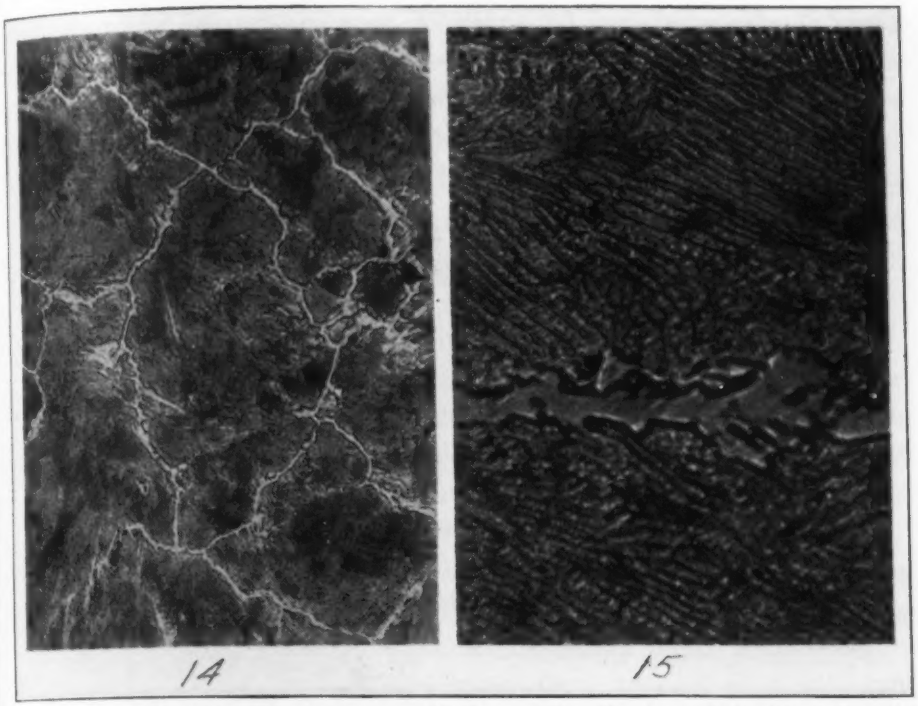


Fig. 14—Photomicrograph of Specimen Similar to Fig. 13—After Carburizing According to the McQuaid-Ehn Test. The Structure Consists of Pearlite with an Excess of Cementite Around the Grain Boundaries. Specimen Etched with Picric Acid. Mag. 100X. Fig. 15—Photomicrograph of Specimen Similar to Fig. 14—at a Higher Magnification. 1000X.

gas might be the cause of the abnormal structure obtained on carburizing the deposited metal.

In order to obtain the helium free from nitrogen, magnesium wire was heated in the container by means of the electric current. The magnesium combined with the nitrogen leaving the pure helium.

After purifying the helium by the method described, a weld was made in this gas. Fig. 13 shows the structure of the material deposited and consists of pearlite, a few particles of cementite, and ferrite. The small round particles are blowholes.

The deposited metal was next carburized according to the McQuaid-Ehn test as previously described. Fig. 14 shows the structure obtained at 100 magnification and can be seen to consist of pearlite with the excess cementite around the grain boundaries which is characteristic of normal steels. Fig. 15 shows the same structure at 1000 magnification from which it can be seen that lamellar pearlite is present with the excess cementite on the grain boundary.

The results from these tests show that normal carburizing

steels can be produced by welding, providing an inert atmosphere surrounds the material during the welding process. The tests also confirm the results obtained in welding in a nitrogen atmosphere as the nitrogen in the helium caused abnormal carburizing steel and it was only after the removal of the nitrogen that normal steel was obtained.

Conclusions

The experiments show that abnormal carburizing steels are produced in steels deposited by means of the electric arc in atmospheres of carbon monoxide, carbon dioxide, nitrogen, and air. Normal carburizing steel was obtained if the metal was deposited in a pure inert gas such as helium.

The effect of the arc using iron electrodes on nitrogen, carbon monoxide, and carbon dioxide was studied. The results show that carbon monoxide forms carbon dioxide with formation most likely of both iron oxide and iron carbide. The gas analysis indicates that a volatile iron-carbon monoxide compound which does not condense at ordinary temperatures and which is not absorbed by the reagents used for ordinary gas analysis may have been formed during the welding operation.

Carbon dioxide breaks down into carbon monoxide and oxygen which causes oxidation of the iron. There is again an indication of a volatile compound being formed due most likely to the presence of the carbon monoxide.

Nitrogen combines with the iron to form the nitride, part of which is retained in the metal deposited and can be identified by microscopic examination and part of which condenses on the sides of the container.

The arc was maintained easiest in the nitrogen atmosphere and was most difficult to maintain in the helium atmosphere.

Acknowledgement

The author wishes to acknowledge his indebtedness to Dr. O. E. Harder for the assistance and suggestions given while carrying on the experimental work as well as in the preparation of the manuscript. He also wishes to thank Dr. R. L. Dowdell for his suggestions, and Miss Carrie H. Green for her aid in making the photomicrographs.

The Author

Ludwig J. Weber was born at St. George, Minn. He entered the University of Minnesota in 1916, taking the course in chemical engineering. In 1920 he received his Bachelor of Science degree. He continued his studies there, receiving his Chemical Engineer's degree in 1921 and his Ph. D. degree in 1924. He was appointed instructor in metallography at the University of Minnesota in 1923, which position he holds at the present time.

LUDWIG J. WEBER

Dr. Weber is a member of The American Chemical Society and American Society for Steel Treating. The present paper on electric welding is the first that Dr. Weber has presented before this Society.

DISCUSSION

Written Discussion: By P. Alexander, General Electric Co., Lynn, Mass.

The author considers Dr. Weber's paper a very interesting one in that it introduces the novel idea of applying the McQuaid-Ehn test to the investigation of arc welds. McQuaid and Ehn in their investigation of abnormal steel applied the carburizing test to the oxyacetylene weld, but I believe, Dr. Weber is the first to publish the results of a systematic investigation by this method of the electric welds.

We are looking forward to finding some reliable method of ascertaining the quality of the metal in the finished weld. *If it be possible* by chipping off a small specimen and examining it in accordance with the McQuaid-Ehn test to judge the soundness of the metal, it certainly will be a decided step forward.

The results of the experiments recently conducted by the writer on electric welds tested by the McQuaid-Ehn method are in many cases similar to those obtained by Dr. Weber.

On the other hand, the conclusions reached by Dr. Weber differ considerably from those reached by the writer and in his opinion are open to considerable criticism.

It is understood that the subject of Dr. Weber's paper is the effect of the arc on gases and action of the latter on the arc-deposited metal. Therefore, the electrical side of the experiments will not be discussed in detail. It will be

noted, however, that Dr. Weber's observations with regard to the stability of the arc in carbon dioxide and its instability in helium are exactly opposed to the writer's experience.

The instability of the arc in carbon dioxide should be expected as the dissociation of this compound in the vicinity of the arc core into carbon monoxide and oxygen absorbs a large amount of energy. Contrary to Dr. Weber's observation the writer found the arc in carbon dioxide unstable.

In discussing the effect of the arc on gases, it must be pointed out at the start that the arrangement of Dr. Weber's experimental apparatus was such that the gases were practically saturated with moisture. Therefore we should expect water vapor to take an active part in the chemical reactions.

For instance, at a moderately high temperature the reaction between carbon monoxide and water vapor will result in further oxidation of the first and liberation of hydrogen as follows:

$$H_2O + CO \rightarrow H_2 + CO_2$$

This is the well known method of production of hydrogen from water gas, thus:

In the presence of iron oxides

$$H_2O + CO + H_2 \rightarrow 2H_2 + CO_2$$

It may be observed that this reaction will explain the presence of 3.8 per cent of carbon dioxide in the carbon monoxide analyzed after the welding.

The liberation of hydrogen explains also the unabsorbed and unidentified gas in the apparatus after the welding. The analysis of the carbon dioxide indicates 4.7 per cent and that of the carbon monoxide 5.8 per cent of unidentified gas. This is again in accord with the reaction suggested above, as in the case of carbon dioxide only a part of that gas was reduced into carbon monoxide.

Dr. Weber's assumption of the production of some unknown volatile carbonyl compound is not substantiated by any experimental proof, and can be considered only as his personal opinion.

On page 433 there is a statement that the soot condensed on the side of the container was analyzed and found to consist of 51.9 per cent of iron and some black material resembling graphite. Dr. Weber concludes that the examined soot must have been a carbonyl of the formula $Fe(CO)_2$. This statement should be substantiated by more complete analysis as the three known carbonyls namely, tetra, penta, and nona carbonyl do not answer to the above formula.

It would seem that another explanation could be given to the origin of the observed soot. During the welding a considerable amount of iron vapor *and small droplets of molten iron* are projected from the crater of the arc and the tip of the electrode. This material accumulates as a layer of fine powder on the walls of the container. If the gaseous atmosphere contains oxygen or water vapor the surface of the *metallic globules* will be covered with ferroso-ferric oxide, which gives a dark appearance to the deposit.

Besides the iron vapors and molten droplets at least a part of the carbon contained in the electrode is liberated during the passage through the arc and condenses on the weld and on the walls of the container.

It may be suggested that the soot observed by Dr. Weber could be a mechanical mixture of oxidized iron particles and fine graphite powder. The carbon content of 0.05 of one per cent in the electrode is sufficient to produce that dispersed graphite powder. The other source of carbon is the carbon monoxide which in the presence of finely divided iron decomposes thus: $2CO=C+CO_2$.

On page 435 it is stated that when the welding was done in nitrogen the same soot was found on the walls of the jar and that analysis indicated 90.3 per cent of iron. Therefore it is assumed that the compound was an iron nitride of the formula Fe_5N_2. It is regretted that the compound was not analyzed for nitrogen. It would seem that the origin of soot could be explained here in the same way as in the case of other gases.

The McQuaid-Ehn test was developed by its originators as a result of their long and systematic study of the causes that impare the hardening properties of steel. Messrs. McQuaid and Ehn established with a very high degree of probability, if not absolute certainty, that one of the principal causes of the occurrence of abnormal carburizing steel is oxygen. It was suggested by other investigators that nitrogen also might be the cause of different behaviour of steel. Yet the McQuaid-Ehn conclusions rest on a solid foundation of abundant experimental data and, whatever the other causes might be, oxygen seems to be the principal cause of trouble.

On page 438 Dr. Weber states that although the cause of abnormal carburizing steel might be due to either oxides or nitrides, the previous experiments have shown that nitrides cause abnormal carburizing steel. It is also stated that the effect of oxygen alone present in steel as oxides or as a gas, on the carburizing properties of steel has as yet not been determined.

The writer does not agree with these conclusions and wishes to point out that Dr. Weber's results do not show clearly enough that nitrogen is the cause of the abnormal steel.

On the contrary, the welds produced in carbon dioxide and carbon monoxide which show after carburizing quite abnormal structure, point in the opposite direction. Even the welds produced in nitrogen are not a sure indication that nitrogen is the main cause. It must be remembered that the nitrogen used in Dr. Weber's experiments was saturated with moisture and contained 0.6 of one per cent of oxygen.

Dr. Weber reports the normal carburizing steel only in case of helium purified with incandescent magnesium.

The writer would observe that this treatment eliminated from helium not only nitrogen but oxygen and water vapor as well.

The recent investigation conducted by the writer on the relationship between physical properties of the arc-deposited metal in different gases by various tests, including the carburizing McQuaid-Ehn test indicates that one of the principal causes of abnormal carburizing properties of steel is oxygen. The following photomicrographs taken on various samples previously subjected to the physical tests indicate almost normal carburizing steel in welds produced in nitrogen.

Abnormal steel was observed in welds produced in carbon dioxide, and various mixtures of argon with oxygen.

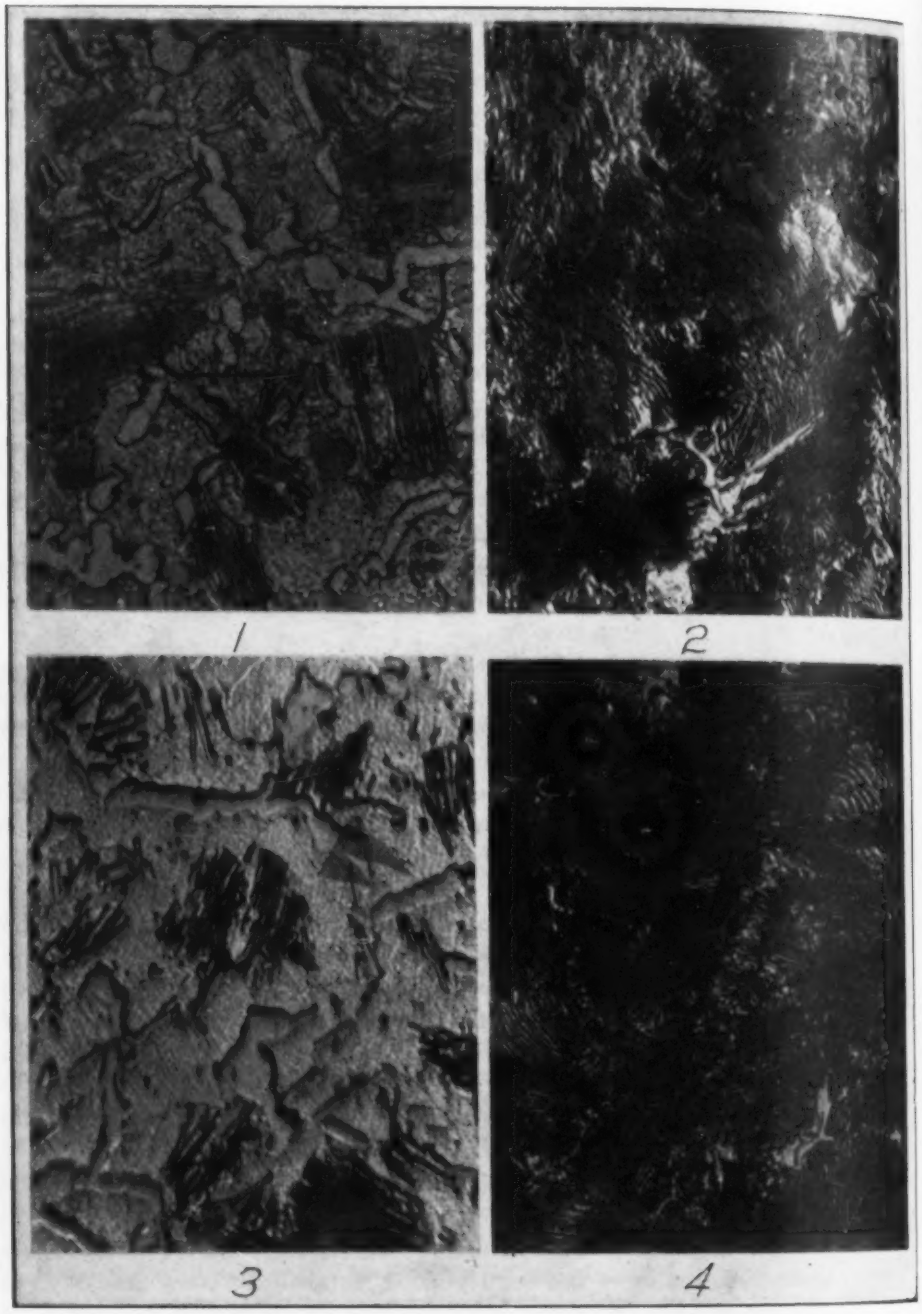


Fig. 1—Armco Iron Weld in Argon 99.5 per cent and Oxygen 0.5 per cent. Fig. 2—Roebling Weld in Nitrogen 40 per cent and Argon 60 per cent. Fig. 3—Roebling Weld in Argon 89 per cent and Oxygen 11 per cent. Fig. 4—Armco Weld in Nitrogen 100 per cent. All Specimens Carburized at 1650 degrees Fahr. for 6 Hours. Cooled in the Furnace. Etched with Picric Acid. Mag. 500 X.

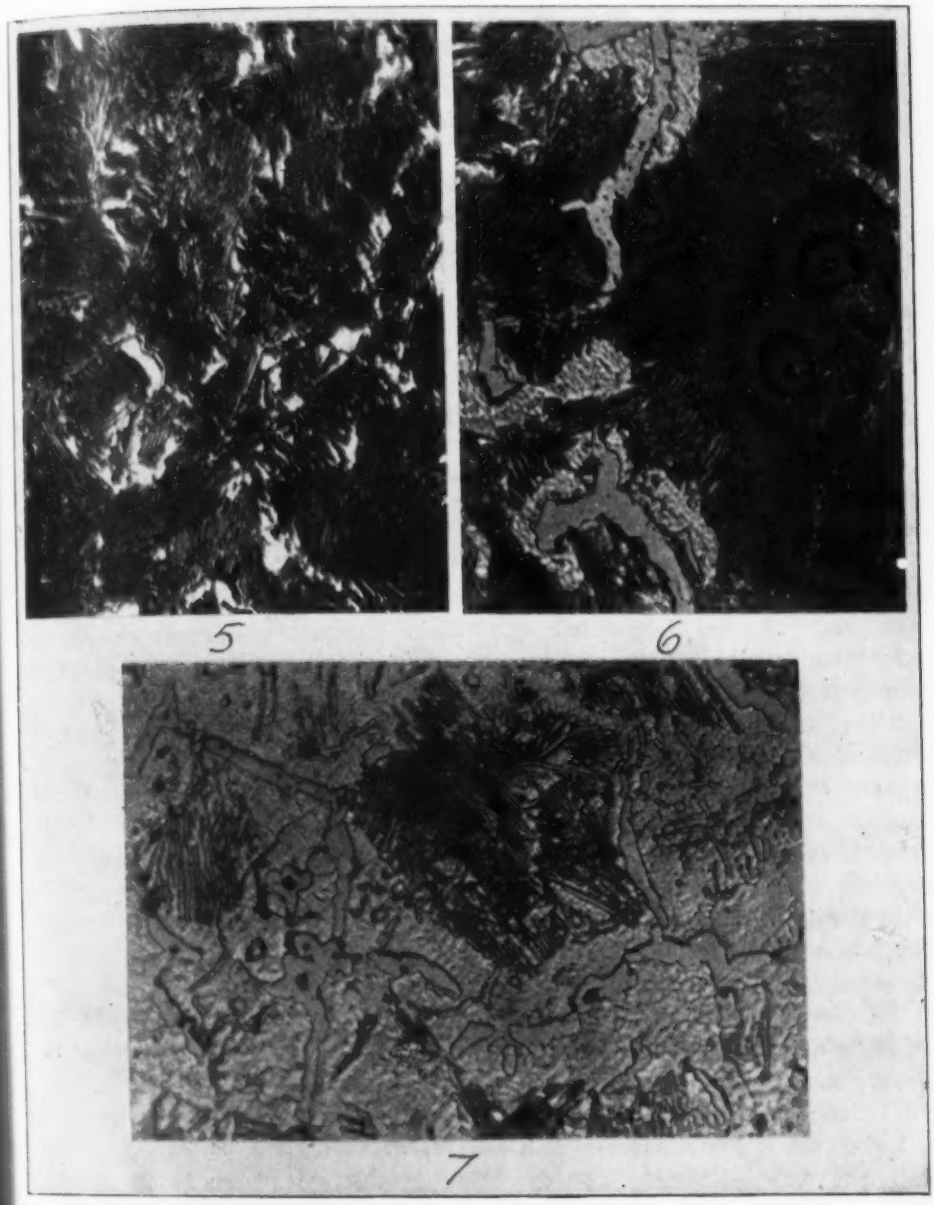


Fig. 5—Roebling Weld in Helium. Fig. 6—Armco Weld in Carbon Monoxide. Fig. 7—Armco Weld in Carbon Dioxide. All Specimens Carburized at 1650 degrees Fahr. for 6 Hours. Cooled in the Furnace. Etched with Picric Acid. Mag. 500 X.

The intermediate stage was observed in welds produced in carbon monoxide and in nitrogen argon atmosphere and helium.

The welds were produced with standard Armco and Roebling welding wire in a stream of dry gas of known composition. The gases were analyzed for impurities before the welding.

GAS	IMPURITIES
Helium	N_2 traces
	O_2 trace
Argon	O_2 0.5 of 1%
Carbon Monoxide	O_2 trace
	CO_2 none
Carbon dioxide	O_2 0.5 of 1%
Nitrogen	O_2 0.3 of 1%

The analysis of the electrodes is given here below:

Roebling	C	0.16	Armco	C	0.07
	Mn	0.4		Mn	0.04
	Si	0.02		Si	0.00
	S	0.03		S	0.03
	P	0.03		P	0.02

The photomicrographs taken on the welds after annealing and before carburizing indicated a percentage of carbon in all welds of about 0.05 of one per cent.

The gases before admission to the steel container in which the welds were produced were dehydrated by $CaCl_2$. Nitrogen was passed also through a hot tube containing iron and copper filings and rendered practically free from oxygen.

The foregoing photomicrographs were taken on specimens related in an identical way. The samples were carburized in the box for 6 hours at 1650 degrees Fahr. and cooled slowly in the furnace. This treatment did not develop the hypereutectoid structure in the specimen produced in nitrogen, which is necessary for determination with certainty of the normal or abnormal structure. However, the comparison of all the photomicrographs indicates quite clearly that oxygen is one of the principal causes of abnormal structure. The increasing percentage of oxygen in any gaseous mixture intensifies the abnormal structure in the deposited metal.

Nitrogen on the contrary does not act in a similar way and even if it be the cause of the abnormal structure, its action is not nearly as effective as that of oxygen.

In conclusion of this discussion, it may be stated that, in spite of the fact that the writer disagrees with Dr. Weber on certain points, he considers his paper very interesting and deserving considerable attention, as it introduces a novel method of testing electric welds.

Written Discussion: By S. W. Miller, Union Carbide and Carbon Research Laboratories, Inc., Long Island City. N. Y.

Any attempt to make more clear the reactions occuring during fusion welding is worthy of commendation, and the carrying out of the very complete plan of Dr. Weber will doubtless result in much addition to our knowledge, which will help to improve the quality of fusion welds, that are so largely used in all branches of industry.

The practical difficulties and expense in the way of commercial welding in any other atmosphere than air seem to be great. If the conclusions

of the paper be correct, helium is the only gas that gives a normal carburizing steel, and its use is, of course, out of the question.

The conclusions may be called in question for a number of reasons.

It is stated that the voltage used was from 60 to 80. If this is the arc voltage, it is much too high for good work, which can be done by a good welder at from 18 to 20 volts.

It is well known that a long arc produces a weld of inferior quality. If the voltage given is that of the open circuit, it would be necessary to know the arc voltage in each case, if accurate comparisons were to be made.

An ordinary generator is not suitable for arc welding, because of its characteristics, though it may be that a regular welding machine of the motor-generator type was used. An ordinary generator would probably account for some of the difficulty experienced in getting good welds.

Speaking generally, the physical properties of the welds are probably the important criteria. Doubtless, due to the difficulty of getting sound welds, physical tests were omitted, and it is to be hoped that Dr. Weber will carry out further tests that will give this important and necessary information.

No chemical analyses of the weld metals are given, and I feel that these are absolutely necessary, especially with regard to carbon, to a proper interpretation of the structure, as the appearance of pearlite and which I believe to be the iron—iron carbide—iron nitride eutectoid are so similar in many cases, that the latter may be called pearlite in error. For complete information, oxygen and nitrogen should also be determined.

There may also be raised objections to the use of impure gases, and to the varying atmosphere in which the work was done. How much these affected the desired results is not possible to say, but it would seem to be better to pass a stream of the gas over the specimen in a confined space to be sure of determining the effect on the metal, this being the object of the tests, what happened to the gases seeming to me of little importance.

These uncertainties of procedure make the results uncertain, and it is hoped that the tests will be repeated using greater precautions.

I doubt very much that any of the structures of the uncarburized metal really contain carbide, except in very small amounts. While the analysis of the wire is not given, the structure of Figs. 5, 7, 8, 10 and 11 are characteristic of welds made with regular arc welding wire containing about 0.15 per cent carbon, and such welds, even when made with a very short arc, never contain more than about 0.04 per cent carbon, so that the plates, (they are such rather than needles), cannot be cementite, and the eutectoid must be made up almost entirely from iron nitride. It might be further said that hypoeutectoid steel never has cementite plates in the grains.

Following the above, I think that Fig. 4 really shows the iron-iron nitride eutectoid. The reproduction seems to show that the etching was quite heavy, and that there are heavy shadows cast by some grain edges,

so that these should not be mistaken for eutectoids. The same remarks apply to Fig. 2, except that the shadows are less prominent.

I certainly hope that the author will determine accurately the effect of the atmosphere on the metal, but I believe he could well afford to neglect the effect of the arc on the gas used.

Written Discussion: By Dr. W. R. Whitney, General Electric Company, Schenectady, N. Y.

The parallel line of work done by Langmuir[1] and Weinman[2] and Alexander[3] on welding in an atmosphere of hydrogen gas dovetails so well with the researches of Dr. Weber that explanatory references at least to each of them might be properly included in the discussion of Dr. Weber's paper in this publication.

Mr. Alexander, by welding in an atmosphere of hydrogen has extended the series of gases one step further so that we now have data on chemically oxidizing gases, such as air; a so-called inert gas, such as nitrogen, which is shown by Dr. Weber to be really not chemically inert in this case, but has been shown by Mr. Alexander to be perfectly inert when free from oxygen or when admixed with a small amount of hydrogen; a reducing gas (carbon monoxide) which might have been thought sufficiently reducing to correspond to hydrogen in effect, but has in reality been shown by Dr. Weber to be chemically active or an oxidizer. Carbon monoxide also deposits carbon in the iron when welding, similar to its reaction in the blast furnace.

Helium, being quite inert, would seem to complete the gas series, but the two kinds of hydrogen, molecular and atomic, add considerably to it. Arcs in hydrogen give welds which are oxide free and even reduce oxides, which may be in the original sample, to leave the weld in a very pure and ductile condition.

Atomic hydrogen, owing to the higher local temperature produced and the extraordinary reducing power of hydrogen atoms, produces pure metal welds in aluminum or even in the case of alloys such as duriron and the stainless steels.

The heat generated at the welding surface in the atomic hydrogen process is sufficient to melt even tungsten which melts at 3380 degrees Cent.

Langmuir and his co-workers are measuring the rate of heat flow per unit area per unit time at a metal surface in the different welding processes, and preliminary measurements indicate that a maximum energy of 1400 watts per square centimeter may be obtained in the atomic hydrogen process, while the oxyacetylene process will give a maximum of 700 watts per square centimeter of surface.

Written Discussion: By G. R. Brophy, General Electric Company, Schenectady, N. Y.

The evidence presented by Dr. Weber strongly supports the theory that nitrogen is a large factor in the abnormality of carburizing steels.

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[1]Langmuir: Flames of Atomic Hydrogen. *General Electric Review*, Vol. 29, No. 3, 153, 1926.

[2]Weinman and Langmuir: Atomic Hydrogen Arc Welding. *General Electric Review*, Vol. 29, No. 3, 160, 1926.

[3]Alexander: Arc Welding in Hydrogen and Other Gases. *General Electric Review*, Vol. 29, No. 3, 169, 1926.

Similar evidence has been presented by W. E. Ruder and the writer in a paper published in *Chemical and Metallurgical Engineering*, November 9, 1921, wherein are reported abnormal structures resulting from the action of nitrogen on high carbon steels. H. J. French has also suggested nitrogen as a possible cause for abnormality, since the conditions under which abnormal steels are made are ideal for the introduction of nitrogen as well as oxygen.

The author states that no suitable etching reagent is known to distinguish between nitride and carbide. Several writers have recommended reagents and in Data Sheet A-3, Handbook A. S. S. T. the best of these are listed. They have been tried and proved by the writer. Using proper reagents will probably show that the "pearlite area" spoken of in Fig. 8 is a nitride patch since its appearance suggests strongly this constituent.

Oral Discussion

DR. J. F. COMSTOCK: Dr. Weber seems to have overlooked the fact that nitrogen may be the cause of structures in steel that by the ordinary method of etching with nitric acid cannot be distinguished from constituents due to carbon. Many of the constituents shown in his slides as pearlite or cementite looked very much like nitrogen compounds. These compounds can usually be distinguished from carbon compounds by etching with cupric chloride as suggested by Mr. Ruder. Data Sheets A3 and A4 of the A. S. S. T. HANDBOOK give some useful informatoin on this subject.

Closing Discussion

DR. WEBER: The experiments in the helium atmosphere were carried out in order to determine whether the water vapor really had a great effect on the deposited metal. The welds in some cases were made several days after the removal of the nitrogen so that water vapor should be present the same as for the other welds. However, all of the points brought up seem to show that in order to get definite data further investigation will have to be done.

Educational Section

These Articles Have Been Selected Primarily For Their Educational And Informational Character As Distinguished From Reports Of Investigations And Research

FACTS AND PRINCIPLES CONCERNING STEEL AND HEAT TREATMENT—Part XI[1]

By H. B. Knowlton

Abstract

This article takes up the influence of chromium upon the properties of steel. Guillet's diagram showing the structural composition steels of varying chromium and carbon contents is discussed. The composition, properties, uses and methods of heat treating of a number of types of chromium steel are described. Stainless steel and the principles of corrosion are briefly considered.

Chromium and Chromium Steels

Of all of the elements which may be added to a simple steel to produce an alloy steel there is probably none which is used for as wide a range of steels as chromium. Steels in which chromium is the only alloying element are known as simple chromium steels and have been made with carbon contents varying from 0.10 per cent to well over 1.00 per cent. In addition to this, chromium is used in conjunction with nearly all of the other alloying elements. Thus we have the chromium-nickel, chromium-vanadium, chromium-tungsten, chromium-tungsten-vanadium, chromium-molybdenum and nickel-chromium-molybdenum steels. In the manufacture of tool steels and valve steels, chromium is used in conjunction with manganese and silicon and cobalt. It seems fair to say that chromium is the most universal in its application of all of the alloying elements.

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[1] This is the eleventh installment of this series of articles by H. B. Knowlton. The several installments which have already appeared in Transactions are as follows: March, June and October, 1925; January, April, May, June, August, October and December, 1926.

The author, H. B. Knowlton, member of the Fort Wayne Group of the Society, is metallurgist of the Fort Wayne Works, International Harvester Company, Fort Wayne, Ind.

The influence of chromium in steels is somewhat different from that of nickel for while the nickel dissolves only in the iron or the ferrite, the chromium combines with the carbon. The cementite in a chromium steel contains both iron carbide and chromium carbide. The effect of the chromium is to increase the hardening power of the carbon in the steel. The chromium carbide seems to be more stable than iron carbide. It requires a higher temperature to dissolve the chromium carbide into austenite. In other words it may be said that chromium raises the critical point on heating (the Ac point). On the other hand it lowers the Ar point or the critical point on cooling. Probably for this reason chromium steels can be hardened with a slower speed of cooling than the corresponding carbon steels. Some of the low carbon low chromium steels may require a water quench to develop the best physical properties. If the content of the carbon or the chromium is increased, oil quenching may be sufficiently fast to produce the desired results. The steels with the highest chromium content are air hardening. It is often said that the hardness penetrates deeper in steels containing chromium. This is due to the fact that the chromium steels will harden with a slower speed of cooling. It is obvious that the surface of any steel cools faster than the layers below the surface, when the steel is quenched in water or oil from the hardening temperature. One of the functions of chromium is to cause the layers beneath the surface to harden in spite of the fact that they do not cool as fast as the surface. With large sections it is necessary to use either a higher chromium or higher carbon content than in the case of small sections in order that the heat treatment may affect the steel all the way through.

The constitution diagram for simple chromium steels is shown in Fig. 1. This diagram shows the typical structures of steels containing various amounts of carbon and chromium after slow cooling from above the upper critical point. It may be noted that this diagram is similar to the one previously given for nickel steels. The chart is divided into three areas. The lowest of these is the pearlitic. All steels whose composition place them in this area have a pearlitic structure after slow cooling from above the upper critical point. The steels which fall in the center area have a martensitic structure after slow cooling from above

the upper critical point, while the steels in the upper zone have a cementitic structure, that is they are composed of carbides of iron and chromium imbedded in martensite.

Low Chromium or Pearlitic Chromium Steels

From the standpoint of practical application, the pearlitic chromium steels are by far the most important of the three classes of chromium steels. This class includes low carbon steels con-

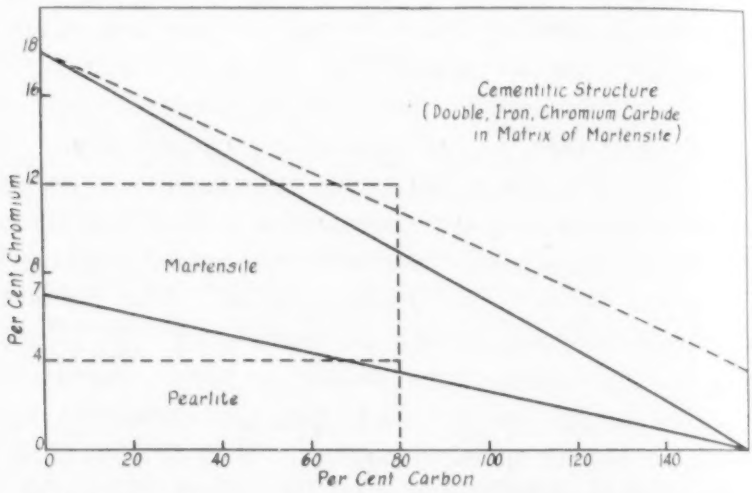

Fig. 1—Constitution Diagram of the Simple Chromium Steels. *After Guillet.*

taining up to about 7 per cent chromium, 0.80 per cent carbon steels containing 4 per cent chromium or less, 1.20 per cent carbon steel with less than about 2 per cent chromium, etc. The limits of composition for pearlitic chromium steels are shown by the lower diagonal line on the diagram.

The properties of these steels are similar to those of the corresponding plain carbon steels except that greater hardness and strength in proportion to toughness can be obtained in the case of the chromium steels. As already mentioned chromium steels may be hardened with a slower rate of cooling, hence a deeper penetration of hardness may be expected. The heat treatments are also somewhat similar to those of the plain carbon steels except that in some instances the quenching temperatures may be slightly higher and the speed of quenching somewhat slower. It will be impossible in this article to give a description of all of the chromium steels, their composition, properties, heat treat-

ments and uses. A few examples are given to show the influence of chromium on the properties and uses of pearlitic steels.

Case Hardening Chromium Steels

Low carbon chromium steels are used for case hardening. They are particularly advantageous for case hardened parts which require extremely hard wearing surfaces. Balls, rollers, and races for bearings are frequently made from this type of steel and case hardened. The chromium steels are also recommended for other case hardened parts such as gears, pins, and shafts which require a hard uniform case.

The following are two typical specifications given for the chemical analysis of case hardening chromium steels.

	S.A.E. 5120 Per Cent	Steel Co. Per Cent
Carbon	0.15 -0.25	0.10-0.20
Manganese	0.30 -0.60	0.30-0.60
Phosphorus	0.04 max.	0.04 max.
Sulphur	0.045 max.	0.04 max.
Silicon		0.25 max.
Chromium	0.60 -0.90	0.55-0.75

The case hardening treatments for these steels are similar to those of the plain carbon steels except that the quenching temperatures may be slightly higher and the quenching bath should be oil and not water. In some cases normalizing may be necessary before case hardening.

Medium Carbon Chromium Steels

There are a number of chromium steels which fall in the medium carbon range. Fig. 2 which was copied from one of the steel companies shows the physical properties produced on a 0.30 per cent carbon 0.90 per cent chromium steel by quenching in water from above the upper critical point and tempering to different temperatures. The figures given were obtained by heat treating 1-inch round specimens. Similar treatments applied to smaller pieces would produce higher strength and hardness and less toughness, while the reverse would be the case if the treatments were applied to larger sections.

The following recommendations are made with regard to forging and heat treating:

Forge	1950-2250 degrees Fahr.
Normalize	1575 degrees Fahr., Cool in air.
Quenching Temperature	1525 degrees Fahr.
Quenching Medium	Water

It might be noted that with this steel as with many alloy steels, the normalizing treatment is quite necessary, if the steel is forged at a high temperature such as that given above. In fact, normalizing is probably more important in the case of the alloy steels

C	Mn	P	S	Si	Ni	Cr	V	Mo
0.28 0.33	0.60 0.80	0.04	0.04	0.25		0.80 TO 1.00		

Critical Points Deg. F. Ac_1 1370, Ac_3 1470, Ar_1 1290

Test Piece Size 2" x 050" Where Taken

HEAT TREATMENT

Operation	Size Treated	Temp. Deg. F.	Time Heating	Time at Heat	Heating Medium	Cooling Medium	Temp. Cooling Medium	Cooling Time
Normalize	1" Rd.	1575				Air		
Anneal		1550				Furnace		
Quench		1525				Water		
Forge		1950-2250						

Tempered as Indicated	Tempering Medium							
Brinell	430	408	385	360	321	293	248	217
Shore	61	58	57	54	52	48	43	37
Rock'ell								

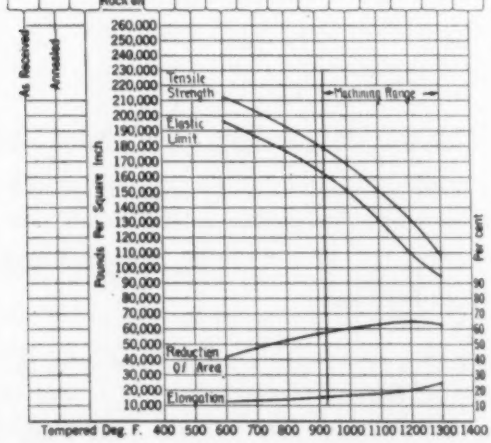

Fig. 2—Physical Properties Chart of a Chromium Steel of Composition Shown.

than it is in the case of plain carbon steels although it is recommended for both. Bar stock which has been properly handled in the mill may not need normalizing. This type of steel is recommended for parts requiring great strength and toughness. Axles, steering knuckles, and shafts fall in this class.

The same steel company recommends a steel containing 0.33-0.37 per cent carbon and 0.80-1.10 per cent chromium for larger parts requiring approximately the same degree of strength and toughness. Water quenching is recommended for parts having

sections more than 1-½ inches thick. The chromium content coupled with the slightly higher carbon causes a deeper penetration of the hardening effect. When large pieces of plain carbon steel are heat treated a higher hardness and greater strength is produced in the outer layers than in the center. It is claimed for this type of chromium steel as for some other alloy steels

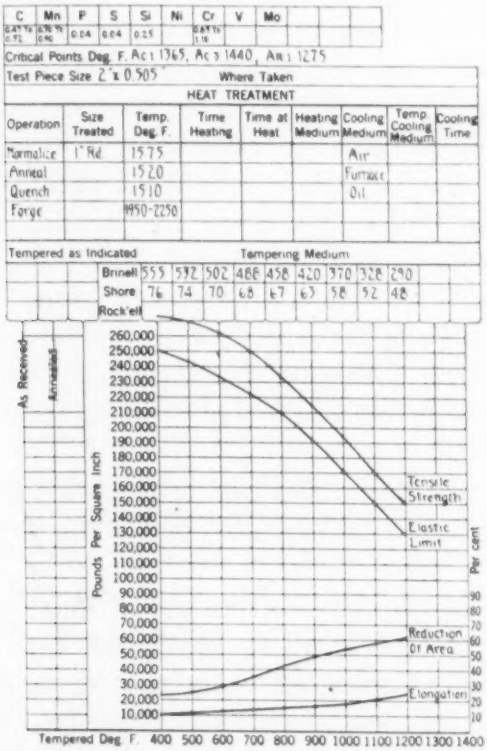

Fig. 3—Physical Properties Chart of a Chromium Steel of Higher Carbon and Chromium Content.

that the physical properties produced by heat treating large sections will be more nearly uniform from outside to center. Small sections of this type of steel may be quenched in oil with satisfactory results. The Society of Automotive Engineers gives a specification for a steel of the same chromium content but containing 0.35-0.45 per cent carbon. This steel is recommended as an oil hardening steel for parts requiring greater strength and toughness than are obtainable with plain carbon steels.

A steel containing about 0.50 per cent carbon and 1.00 per cent chromium is recommended for parts requiring not only strength and toughness but considerable hardness as well. Auto-

mobile transmission gears may be made of this type of steel. By proper heat treatment a scleroscope hardness of about 75 may be produced combined with high strength and a good degree of toughness. Fig. 3 shows the physical properties which may be produced by various heat treatments applied to this type of steel. It would not be possible to produce such combinations of strength, hardness and toughness by the use of a plain carbon steel. If the carbon content were increased sufficiently to produce the high hardness, the toughness would be decreased. The advantage of the chromium is that it increases the hardening power of the carbon without causing a corresponding decrease in the toughness of the steel. This type of steel is also recommended for shear blades, hammers, dies and other parts requiring hardness, strength and toughness.

The higher carbon chromium steels are used largely for tools and for parts requiring great hardness. Camp and Francis mention the use of the following high carbon chromium steels:—

0.90 per cent carbon—2.00 per cent chromium for rolls for cold rolling metals.

1.30 per cent carbon, 0.50 per cent chromium for files.

0.65 per cent carbon, 0.75 per cent chromium for axes and hammers.

Along this line it may be mentioned chromium in varying amounts from 0.25 per cent up to several per cent have been used in quite a number of different types of tool steels.

Probably one of the most important uses of high carbon chromium steels is in the manufacture of bearing races, balls and rollers, thrust washers and other similar parts requiring maximum hardness, deep penetration of hardness, and uniformity of hardness. Ball and roller bearings, having single points or lines of contact between the ball or rollers and the races, must withstand great unit pressures and at the same time be resistant to wear. Furthermore, if the hardness is not uniform, the balls or rollers may wear flat-sided or the races may wear nonuniformly. When it is considered that balls are inspected and sorted to 0.0001 inch, it may readily be seen how important this is.

Ball and roller bearing parts are usually made either of the high carbon chromium steel or else of low carbon alloy steel.

When the latter is used a case hardening treatment must be employed.

S. A. E. Specification 52100 covers the high carbon type of steel. It calls for the following analysis:

	Per Cent
Carbon	0.95-1.10
Manganese	0.20-0.50
Phosphorus	0.03 max.
Sulphur	0.03 max.
Chromium	1.20-1.50

This type of steel must be carefully normalized and annealed or it will not machine well nor harden uniformly. It is important that the cementite be in the spheroidized or globular form and that it be evenly distributed. It is often true, however, that bar stock as received from the steel mills has the best structure for machining and hardening. Consequently the user does not need to normalize or anneal the steel. On the other hand if the user heats the steel to a high temperature for forging, he may produce a coarse structure that is difficult to break down. The normalizing and annealing of highly heated 1.00 per cent carbon, 1.00 to 1.50 per cent chromium steel is much more difficult than performing the same operations on plain carbon steel of the same carbon content. The Society of Automotive Engineers recommends the following normalizing treatment for 52100 steel:

Heat to 1650-1750 degrees Fahr.

Cool to 1000 degrees Fahr. black heat by opening furnace.

Reheat to 1300-1350 degrees Fahr. and hold at heat for at least 36 hours or until the desired structure and machinability are obtained. Then cool slowly in the furnace.

It will be noted that this is a long, slow process. The object of the first heating and the cooling to black is to break down the high heat structure. The second heat which is just below the critical point seeks to precipitate the cementite in finely divided evenly distributed globular particles. This treatment is sometimes varied by making the second heat just above the critical point and then cooling extremely slowly in the furnace through the critical point. The usual hardening treatment for this type of steel consists in heating to 1500-1550 degrees Fahr., quenching in oil and tempering to the required hardness. Where extreme

hardness is neeessary a low tempering temperature such as 250-350 degrees Fahr. may be employed. The steel should be held at this temperature long enough to thoroughly relieve strains. This may require one or more hours. The ordinary hardness tests do not give any indication of when the strains are relieved as there may be no measurable decrease of hardness after tempering at such low temperatures, and yet the toughness is increased by relieving the strains.

Martensitic Chromium Steels

Stainless Steel

It might seem from casual consideration that chromium steels which fall in the martensitic area of Guillet's diagram (Fig. 1) would have no commercial application, and yet one of the most important of the simple chromium steels falls in this territory. This is the so called "stainless steel". The patents on this type of steel cover quite a wide range of composition but it is stated that the best composition is about 12.5-14.0 per cent chromium and 0.28-0.38 per cent carbon.

The importance of stainless steel is due to the fact that, as its name implies, it is not easily oxidized or corroded when used in the properly heat treated and finished condition. Stainless steel withstands the action of weather, sea-water, vinegar, fruit, vegetable and meat juices, steam, lubricating, paraffine and cylinder oils, alkalies, dilute solutions of mercuric chloride such as used in disinfecting, alcohol, pure carbon tetrachloride, nitric acid, etc. It does not withstand the action of hydrochloric acid, sulphuric acid, sulphurous acid, ammonium chloride, ferric chloride, chlorine, aqua regia, strong solutions of mercuric chloride, and some other chemicals. Stainless steel withstands oxidation much better than ordinary steel when heated in air to temperatures below 800 degrees Fahr. It is reported that it does not begin to scale until heated to about 1500 degrees Fahr.

It should be noted that these stainless properties do not exist unless the steel is properly heat treated and ground free from all scale and tarnish. If there are spots of scale left on the steel, an electrolytic action may be set up between the clean steel and the scale which would cause oxidation or corrosion of the steel.

It will be impossible in this article to make more than a

casual mention of the principle of electrolytic corrosion. A more complete discussion of corrosion will be found in the American Society for Steel Treating *Handbook*. Briefly, it may be said, that a great deal of the oxidation and corrosion of metals in service is due to an electrolytic or cell action between dissimilar metals or dissimilar portions of the same metal. This action is similar to that taking place in a primary cell or electric battery. For example, if a piece of pure zinc is placed in a solution of ammonium chloride (sal ammoniac) the zinc is not readily dissolved. But if a piece of copper or a carbon plate is placed in the solution with the zinc and the two are connected by a conductor, a cell is formed, and an electric current is generated and the zinc is slowly dissolved. The general rule may be stated as follows: when any two dissimilar metals are joined and placed in a solution which will conduct electricity, an electric current is generated and one or the other of the two metals is dissolved.

In service, it has been found that pure metals do not corrode as readily as impure metals or combinations of metals. For example a steel shaft surrounded by a bronze bushing and exposed to salt water is prone to corrosion at the junction of the steel and the bronze. Similarly a piece of stainless steel containing spots of scale will corrode at the junction of the scale and the clean metal due to the same electrolytic action. It may seem at first glance that this theory fails to explain rusting or oxidation on exposure to weather. However, it must be apparent that the moisture in the air plays a part in the action, because rusting does not take place so readily in dry air. It is probable that a minute portion of the surface of the metal first dissolves in the water or moisture and then is precipitated by the action of the air. Then more metal is dissolved and precipitated, and so on.

A discussion of why the high chromium steels are somewhat corrosion resisting will not be attempted here. Suffice it to say that there are some structures which favor the electrolytic action and some which do not. In general, it would be expected that solid solutions such as austenite would be fairly resistant to corrosion as the structural composition is too uniform to promote an electrolytic action. Similarly, a fine martensitic structure should be more resistant than a pearlitic structure.

Heat Treatment and Structure

As already stated, stainless steel falls in the martensitic area of Guillet's diagram, that is the structure after slow cooling from above the critical point is martensitic. However it is not used in this condition. It is first annealed by prolonged heating

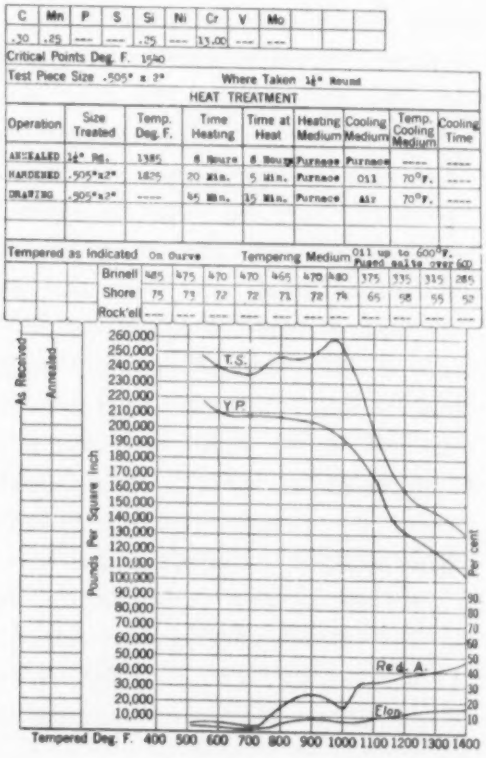

Fig. 4—Physical Properties Chart of a Stainless Steel Taken from A. S. S. T. Handbook.

to a temperature below the critical point. Fig. 4 taken from the American Society for Steel Treating *Handbook* gives the heat treatments and physical properties for this type of steel. It will be noted that the critical point is given as 1540 degrees Fahr. and the annealing temperature as 1385 degrees Fahr. with a soaking time of 8 hours. This is a different treatment from ordinary annealing which consists in heating to above the critical point followed by slow cooling. It corresponds better with the high tempering treatments. The structure produced by this treatment is described by Camp and Francis as consisting of spheroidized particles of iron-chromium carbides (cementite) imbedded in a matrix (or background) of the iron-chromium alloy corre-

sponding to ferrite. When the steel is given this structure it is relatively soft and may be machined or cold drawn.

In order to harden stainless steel it is necessary to heat it considerably higher than the critical point due to the fact that the chromium carbides are not easily dissolved. Temperatures from 1750-1900 degrees Fahr. are recommended for hardening. On account of the high chromium content considerable hardness may be produced by cooling in air from the hardening temperature. Higher hardness values may be obtained by quenching in oil or water. The former is usually recommended for most purposes. The structure and hardness will depend upon the speed of cooling. If the cooling is extremely fast the structure may be largely austenitic. In this case the steel would not be as hard as when a martensitic structure is produced. The heating for hardening should be slow. A total time for bringing the steel up to temperature of two or three times that used for plain carbon steel, is recommended. A thorough preheating to 1300 degrees Fahr. is also recommended.

The curves given in Fig. 4 showing the physical properties after different tempering treatments are quite interesting. It will be noted that there is an increase of hardness and strength when the steel is tempered at 1000 degrees Fahr. Higher tempering temperatures cause a rapid drop in the hardness and strength. The "secondary hardness" at 1000 degrees Fahr. is probably explained by the fact that considerable austenite was retained after the quenching treatment and that the tempering to 1000 degrees Fahr. caused the austenite to be transformed into martensite which is the harder of the two structures. Higher temperatures of tempering causes decomposition of martensite into softer structures.

Uses of Stainless Steel

At first the principle use of stainless steel was for cutlery, particularly table and kitchen cutlery, which must withstand the action of fruit, vegetable, and meat juices, and for surgical instruments which should withstand repeated disinfecting without tarnishing. More recently it has been used for various other purposes such as automotive valves, pump parts, rifle barrels, turbine blades, etc. It is used somewhat for parts which were

formerly nickel plated. Probably on account of the properties which can be produced by air and oil quenching it has been used somewhat for punches and dies.

Stainless Iron

Stainless iron has about the same chromium content as stainless steel but the carbon content is only about 0.15 per cent. This alloy will not be discussed in detail.

High Chromium or Cementitic Steels

The steels which fall in the upper zone of Guillet's diagram are cementitic after slow cooling from above the upper critical point. That is the structure contains considerable cementite imbedded in martensite. Like the previously discussed martensitic steels they cannot be normalized or annealed in the ordinary sense of the words, that is slow cooling from above the critical point will not leave them in a soft or annealed condition. However, it is possible to heat treat some of these steels. The principles of heat treating are similar to those already discussed under stainless steel except that in the case of some of the high carbon steels it is not possible to dissolve all of the excess cementite. The structure so far as the cementite is concerned remains the same after treating as before.

There are a number of corrosion resistant, heat resistant and electrical resistance steels that fall in this class. Besides this there is at least one high carbon, high chromium cobalt steel which is used for "cast tools". That is the steel is cast to nearly the size and shape of the finished tool. No forging operation is required to break down the casting structure. Heat treatments are required in order to soften it for machining or harden it for service. This steel is used primarily for dies. It is an air hardening steel of the type previously mentioned which remains cementitic in spite of the heat treatments. This steel was described in the discussion of alloy tool steels.

Chromium and other Alloying Elements

Chromium is also used in conjunction with other alloying elements in the production of both high and low alloy steels. High speed steels contain 3-4.5 per cent chromium in conjunc-

tion with tungsten, vanadium and sometimes cobalt. This steel falls in the cementitic class. Many of the heat and corrosion resistant steels contain chromium in conjunction with nickel or other elements. The use of chromium with other alloying elements will be discussed in another article.

Chromium Plating

Before leaving the subject of chromium and chromium steels it may be well to make at least a casual mention of the fact that within the past few years chromium plating has become commercially important. Chromium plate is harder than nickel plate, takes a high polish and is not easily oxidized or corroded. It is claimed that when chromium is plated over hardened steel it is very resistant to wear as well as corrosion. The life of plug gages is said to be increased by chromium plating. On the other hand this process is not recommended for cutting tools. Chromium plate may be applied over copper and nickel plate.

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Reviews of Recent Patents

By NELSON LITTELL, Patent Attorney
475 Fifth Ave., New York City—Member of A. S. S. T.

1,616,364, Hack Saw, Howard M. German, of Crafton, Pennsylvania, Assignor to Universal Steel Company, of Bridgeville, Pennsylvania, a Corporation of Pennsylvania.

This patent describes an improved steel for the making of hack saw blades and whereby the wearing of the blades may be improved by having therein free cementite in the form of nodules in the finished blade, embedded in a softer and tougher matrix, usually of martensite, with varying amounts of troostite and sorbite. This improvement gives from 50 per cent to 300 per cent more working life to the hack saw blades. The preferred composition for the carbon 0.90 to 1.50 per cent, tungsten 2 to 5 per cent, chromium 0.50 to 2.50 per cent, manganese, silicon, sulphur and phosphorus within the usual range of crucible and tool steel. The sheets for making the hack saw blades are packed in an annealing box heated to a temperature of around 1350 to 1375 degrees Fahr. and cooled slowly. The sheets are then sheared and shaped to form the hack saw blades and the blades are hardened by heating slightly above the critical point and quenching to produce the nodular cementite in the cutting edge.

1,616,393, Manufacture of Alloy Steels, Byramji D. Saklatwalla, of Crafton, Pennsylvania.

This patent describes the process of making chromium steel, which comprises forming a molten bath of steel with a supernatent slag layer, adding to the metal a reducing agent and into the slag layer an unreduced chromium compound sufficient in amount to furnish the major portion, if not all of the chromium to be added to the steel, and maintaining the bath at a temperature to cause reaction between the reducing agent in the metal layer and the chromium compound in the slag layer to reduce the chromium directly into the metal bath.

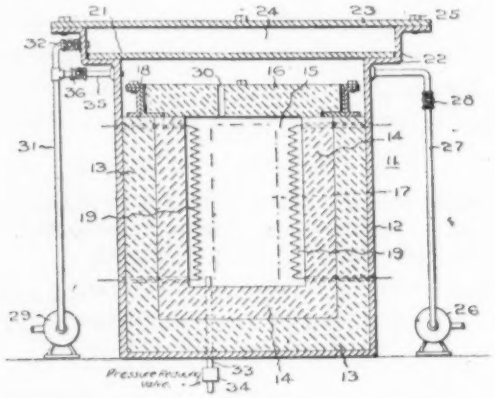
1,617,334, Alloy Steel, Charles Morris Johnson, of Avalon, Pennsylvania, Assignor to Crucible Steel Company of America, a Corporation of New Jersey.

This patent describes an alloy steel which is resistant to corrosion and has valuable mechanical qualities. The steel as formed contains 25.50 to 26.50 per cent chromium, 24.50 to 25.50 per cent nickel, silicon 1 to 3.50 per cent, vanadium 0.10 to 0.30 per cent and may also contain manganese up to 0.65 per cent and the carbon content should not exceed 0.30 per cent.

1,617,359, Heat Treating Furnace, Sigurd Westberg, of Pittsburgh, Pennsylvania.

This patent describes a heat treating furnace comprising an outer casing 11, a refractory lining 13 and an interlining 14 of high temperature heat resistant material and a heat insulating cover 16. The furnace is preferably

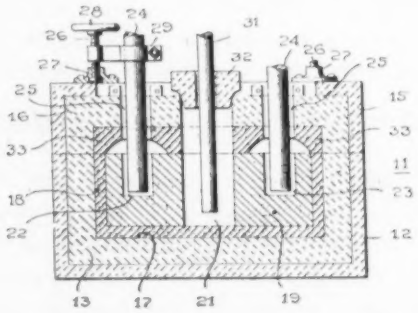
heated by means of a plurality of resistance members 19. A suction pump 26 connected to the upper portion of the furnace chamber permits the gases to be evacuated from the chamber 15 through an opening 30 in the cover, and



a force pump 29 permits the introduction of an inert gas under pressure into the chamber 24, keeping the cover plate 21 in position. To prevent the rapid inrush of atmospheric air into the chamber when the cover is removed, the pipe 35 connected with the pressure pump 29 permits an inert gas under pressure to be introduced into the furnace chamber before it is opened.

1,617,396, **Heat Treating Furnace, Alvin D. Keene, of Pittsburgh, Pennsylvania, Assignor to Westinghouse Electric & Manufacturing Company, a Corporation of Pennsylvania.**

This patent describes an electric heat treating furnace comprising an outer casing 12, a refractory lining 13 and refractory conducting material 19 in the form of blocks. The blocks 19 are provided with a central opening 21



to receive the articles to be heat treated, which are usually of an elongated form, such as a rod 31, and the openings 22 and 23 receive the electrodes 24, the arc is struck between the bottom of the electrodes 24, which is adjusted to the blocks 19 and very quickly heats the entire furnace to the desired temperature, after which by relocating the position of the electrodes 24, by means of the screw 26 and hand wheels 28, the temperature may be maintained quite uniformly at any desired level.

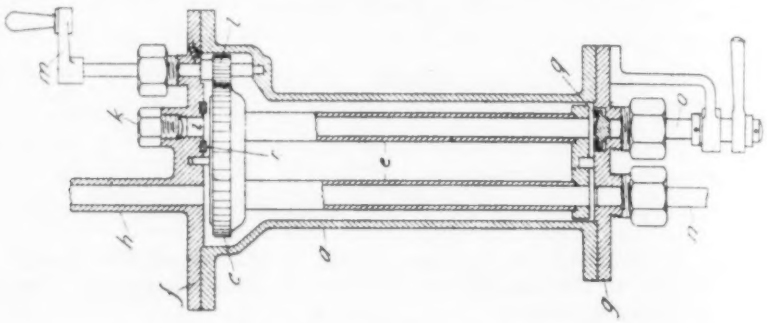
1,617,616, **Process of Rendering Iron and Steel Nonoxidizable and Articles Produced Thereby, Edward G. Caughey, of Sewickley, Pennsylvania,**

Assignor to Edgewater Steel Company, of Pittsburgh, Pennsylvania, a Corporation of Pennsylvania.

This patent describes the process of rendering iron and steel nonoxidizable, which comprises incorporating in the iron as a solid solvent a sufficient quantity of aluminum to form a saturated solution in said solvent at the temperature at which it is desired to prevent oxidization of said iron or steel articles. In the case of an annealing box designed to resist high temperatures, a low carbon steel containing approximately 12 to 15 per cent of aluminum gives satisfactory results.

1,617,136, Electrode Device for Electric Furnaces, Ole Sandvold, Olaf Rye, and Olaf Platou, of Notodden, Norway, Assignors to Norsk Hydro-Elektrisk Kvaelstofaktieselskab, of Oslo, Norway.

This patent describes an apparatus for introducing new electrodes into a closed electric furnace without disturbing the pressure conditions of the gas



within the furnace. The electrode tube is indicated h and to this a chamber a closed at the bottom of the plate g is secured. Storage tubes e are rotatably mounted in the chamber so that the tubes alternately come into axial alignment with electrode tube h. The electrodes may be introduced into the tubes e by the removal of the plug k and then rotated into position below the electrode tubes h and pushed into the furnace by the use of the rod n.

1,617,726, Manufacture of Steel, Frank N. Speller, of Pittsburgh, Pennsylvania.

This patent describes a method of manufacturing steel which permits the heat to be safely held in the teeming ladle for several minutes longer than usual. This result is accomplished through preheating of the bottom of the ladle by charging a quantity of superheated steel into the same sufficient to make up for radiation losses, prior to pouring the regular heat into the ladle.

1,610,567, Annealing of Sheet Steel, Henry S. Marsh and Ralf S. Cochran, Youngstown, Ohio.

The sheet material is heated within a maximum time interval of seven minutes while maintained in a nonoxidizing atmosphere to annealing temperature. It is then cooled within a maximum interval of two minutes while still maintained in a nonoxidizing atmopshere, to a temperature of 1550 degrees Fahr. as a maximum, and still further cooled to a dull red heat within a maximum time interval of two minutes. The sheets are then made into packs and allowed to cool in the air to atmospheric temperature.

Abstracts of Technical Articles

Brief Reviews of Foreign Publications of Interest To Metallurgists and Steel Treaters

X-RAY INVESTIGATION ON THE INTERNAL STRESS IN COLD-WORKED METALS. By Sinkiti Sekido. *Kinzoku no Kenkyu*, Vol. III, No. 10, p. 482-491.

A cold-worked metal is undergoing an internal stress consisting of a large number of pairs of tension and compression locally balancing with each other, the intensity of these stresses varying in a wide range. These tensions and compressions will cause a distortion of the space-lattice, the magnitude of which varies from point to point in the metal. The consequence is that the X-ray spectrum lines are more or less diffused. Hence by measuring the broadening of these lines, the maximum stresses can be evaluated.

The author took the X-ray photograms of cold-worked copper wires, the reduction of which was from $\frac{0.7}{2.2}$ to $\frac{0.3}{2.2}$ mm. in diameter, and which were tempered at different temperatures up to 550 degrees Cent. The width of the lines were measured on the records taken by a Moll microphotometer, and found to decrease with the rise of tempering temperature. The total broadening of the lines in the cold-worked wires was thus found to be,

$$\frac{da}{a} = 0.3 \text{ per cent}$$

a being the lattice-constant, in the mean. The stress corresponding to this strain was found by the formula

$$P = E\frac{da}{a}$$

Since $E = 1.2 \times 10^{12}$,

$$P = 3.6 \times 10^{9} \text{ dynes per cm}^2,$$

which is a little smaller than the maximum tensile strength of copper. As the intensity of the internal stress cannot exceed that of the tensile strength, the above calculation shows that in a severely cold-worked metal, an internal stress approaching its tensile strength actually exists.

Abstracted by Dr. Kotaro Honda, Japan.

THE HEAT OF FUSION AND THAT OF THE NEW TRANSFORMATION IN TELLURIUM. By Saburo Umino, *Kinzoku no Kenkyu*, Vol. III, No. 10, p. 498-501.

By the calorimetric method, the author measured the heat content and the specific heat of tellurium at different high temperatures beyond its melting point up to 550 degrees Cent. He thus found a new transformation at

348 degrees Cent. with a heat of transformation of 0.63 calories. The latent heat of fusion at 446 degrees Cent. was found to be 33.50 calories.

Abstracted by Dr. Kotaro Honda, Japan.

HARDENING OF THE SURFACE OF OBJECTS OF CAST IRON BY MEANS OF THE VOLTAIC ARC. By L. C. Bougaieff. *Metallurgist* (Leningrad) 1926, 2, 85-87.

The author describes a method of hardening of the surface of objects manufactured of cast iron after their ultimate mechanical working. The object to be hardened was connected to one of the poles of a source of electric energy the second pole being formed by a moveable carbon rod, which was systematically moved along the surface of the object in question and which produced the superficial fusion of the cast iron. On account of the rapid transfer of heat to the body of the object the fused portions of it hardened and covered the object with a thin crust of white cast iron, which retained the former degree of smoothness. This method of superficial hardening can also be applied to objects of steel and iron.

Abstracted by M. Oknoff and F. Miller, Leningrad, Russia.

ON THE INCREASE OF HARDNESS OF LOW CARBON STEELS BON STEELS. By Saburo Umino. *Kinzoku no Kenkyu.* Vol. III, No. 11, p. 527-533.

The present writer measured the heats of A_1, A_2 and A_3 transformations by the calorimetric method. The heat content-temperature curves or the specific heat-temperature curves for different kinds of steels were first determined. The heat of A_3 transformation was obtained from the discontinuity at the A_3 point, in the heat content-temperature curve for electrolytic iron, and found to be 5.35 calories per gram of iron.

In the same way, the heat of A_1 transformation was determined for steels containing different amounts of carbon; the result was:

Carbon content (%)	0	0.04	0.13	0.27	0.35	0.77
Heat of transformation. (Cal.)	0	0.67	2.40	4.70	6.00	13.60

Hence the heat of A_1 transforation per gram of carbon is 17.4 calories.

Since the A_2 transformation takes place continuously in a wide range of temperature, its latent heat of the transformation cannot be obtained in the above way. Hence the author first obtained the true specific heat-temperature curve, and then measured the area enclosed by the curve and that of normal cooling; this area gives the total heat of the A_2 transformation. The result of calculation was 3.65 calories per gram of iron.

Abstracted by Dr. Kotaro Honda, Japan.

THE CHEMICAL STABILITY OF GRAY CAST IRONS WITH A SMALL ADDITION OF COPPER. By P. B. Michailoff. *Messenger of metal industry.* Moscow. 1926, 9-10, 5-22.

The author studied the influence of small quantities of copper on the mechanical properties, chemical stability and microstructure of gray cast iron. The studied samples were taken from three different charges. The composition

of the specimens can be subdivided into three groups:

	C	Graph.	Si.	Mn	S	P	Cu
	%	%	%	%	%	%	%
I	3.16-3.40	2.12-2.93	2.00-2.54	0.54-0.66	0.079-0.096	0.36-0.51	0-0.67
II	2.95-3.23	1.84-2.16	1.53-1.63	0.56-0.60	0.12- 0.13	0.34-0.37	0-1.30
III			1.08-1.18	1.38-1.46	0.018	0.25-0.27	0-0.60

The melting of the cast irons in question was effected in a cupola, whereby one part of the blocks under trial was poured without the addition of copper while the other part—after the addition to the ladle of a weighed quantity of copper and a thorough mixing of the metal. The conditions of casting of the blocks under trial were in all cases similar. The results obtained in mechanical testing are contained in the columns 3—5 of the Table I. It can be concluded therefrom, that the addition of copper has only a slight influence on the mechanical properties, sometimes in the positive and sometimes in the negative sense. This induces the author to consider copper as an indifferent constituent. The influence of copper on the solubility of cast iron in sulphuric and hydrochloric acids is marked. The stability of cast iron to these acids augments with the quantity of copper dissolved and attains a maximum at about 1 per cent of copper. This regularity is clearly to be seen from the columns 6—7 of Table I. Such numerical data of solubility are given in the present paper for the following aqueous solutions: 2 per cent—acetic acid, 5

Table I

1	2	3	4	5	6	7
Groups	Percentage of copper	The tensile strength in Kgr./mm²	The breaking up weight for a sample 25x25x 400mm in Kgr.	Brinell hardness Diam.	The loss in weight during 48 hours in % in a 5%-solution of H_2SO_4	in a 5%-solution of HCl
	0,0	20,3	1500	4,00	11,96	10,46
I	0,48	21,7	1450	4,00	3,12	0,97
	0,67	18,4	1325	4,62	0,72	0,46
	0,0	29,0	1500	4,00	10,98	7.41
	0,3	26,4	1600	4,00	5,28	1,41
II	0,6	27,7	1650	4,00	2,74	0,68
	0,9	25,8	1500	3,90	2,25	0,70
	1,0	28,4	1800	3,90	1,94	0,60
	1,3	12,4	1150	3,85	2,95	0,90
III	0,0	19,1	1550	4,20	1,66	0,87
	0,6	21,7	1550	4,30	0,28	0,48

per cent—nitric acid, 30 per cent and 20 per cent—common salt and 9 per cent—sodium hydrate. In respect to these solutions cast iron with an addition of copper usually appears to be more stable, than without it, but the influence of copper appears to be generally much less pronounced and is sometimes hardly to be noticed.

The microscopic study of cast iron proved firstly the total absence of

structurally free copper,—a fact, that proves, that copper forms a solid solution; the author explains in this way the greater chemical stability and sometimes the greater Brinell hardness of the cast irons containing copper. In the cast irons of groups I and II, in which the chief mass is a hypoeutectoidal steel, no presence of copper could be discerned. In the cast irons of group III with a hypereutectoidal fundamental mass the presence of copper could be observed by the diminution of the quantities of free cementite and by the considerable refinement of the separated graphite.

The author considers in conclusion, that cast irons containing copper in a quantity from 0.5 to 1 per cent to be of higher quality, than the ordinary ones, and their application to machine castings profitable.

Abstracted by M. Oknoff and F. Miller, Leningrad, Russia.

THE DETERMINATION OF GASES IN IRON AND STEEL. By Dr. Phil. P. Klinger, Essen. *Stahl und Eisen*, September 16, 1926, p. 1245 to 1254; September 23, 1926, p. 1284 to 1288 and October 7, 1926, p. 1353 to 1358.

In solidified iron or steel gases may occur either enclosed in blow holes (blisters) or dissolved. In former investigations the gases enclosed in blow holes were determined by boring into the cavities in the absence of air and analyzing.

To ascertain the gases dissolved in steel the sample is either heated in the vacuum and the escaping gases are gathered or the steel is dissolved by suitable chemical reagents and by this the gases were set free.

The author gives a summary of the existing investigations and describes his own studies carried out in the Krupp works at Essen.

He employed the following ten methods:

1. Hot extraction in vacuum without addition.
2. Hot extraction in vacuum with addition.
3. Chemical reaction with copper-ammonium-chloride after Goutal.
4. Chemical reaction with mercuric chloride after Goutal.
5. Chemical reaction with copper-ammonium-chloride after Vita.
6. Chemical cold-reaction in vacuum with iodine.
7. Chemical cold-reaction in vacuum with bromine.
8. Chemical cold-reaction in vacuum with mercuric chloride.
9. Chemical cold-reaction in vacuum with cupric chloride.
10. Chemical reaction in vacuum with mercuric chloride after Oberhoffer.

The apparatus used is briefly described, the investigations were carried out with carbon steels manufactured in the basic and acid open-hearth furnace, in the Bessemer- and Thomas converter and in the crucible furnace. In Table 1 may be found the results of the gas analyses of basic open-hearth steel.

The examinations show clearly the relation of the results upon the nature of the method employed. Drawing a parallel of the methods it may be seen that the extraction gives a greater quantity of gas than the chemical reaction; the chief ingredients of the gas mixtures, obtained by the different methods were: carbon monoxide, employing the vacuum-hot extraction method, carbonic acid at Goutal's method and nitrogen at Vita's method; the cold reaction methods in the vacuum yielded the poorest results and not one of the gas components was of a predominant rank.

1. *Hot Extraction Method in Vacuum.* In the literature it is often mentioned that when a steel sample is heated in vacuum it is impossible to obtain the total gas-quantity, which is essentially influenced by the heating temperature, the heating time and by the shape of the sample in opposition to the vacuum heating in the molten state. But the author's investigations proved partly the contrary. In all extraction-determinations it must be borne in mind that the gases obtained were partially reaction-gases.

To ascertain for both of the extraction-methods the time after which the development of gases and the reaction might be considered as finished, there were equal quantities of an open-hearth steel, containing 1.2 per cent carbon and of an electrolytic iron with 0.02 per cent carbon with and without the addition of the tin-antimony alloy heated in the vacuum at about 1100 degrees Cent. (2012 degrees Fahr.) for an hour, then the gases were exhausted and examined. This method was repeated ten times. The development of gas was finished after two hours working without addition and after one hour with addition of the alloy. As the oxygen exists in steel in the form of soluble lower oxide-compositions as ferrous oxide, manganous oxide or in that of enclosed slags as ferric oxide, silicic acid or alumina there were the following four systems to take into consideration:

1. iron, carbon, oxygen.
2. iron, carbon, manganese, oxygen.
3. iron, carbon, silicon, oxygen.
4. iron, carbon, aluminum, oxygen.

To clear up the question of the reduction of the oxygen-combinations by carbon or iron carbide at the appointed experimental conditions, the author annealed pure oxygen-combinations with graphite or iron carbide partially under the addition of pure iron in the vacuum at about 1100 degrees Cent. (2012 degrees Fahr.) The oxygen combined in iron and manganese may be easily reduced by carbon; whereas the oxygen of the silicic acid and of the alumina is only reduced for the smaller part under the same conditions. In the molten state the effect is more intensive. Experiments 23 and 24 show that graphite and iron carbide previously react with the combustion-boat of magnesium oxide under formation of carbon monoxide. The experiments made it probable, that the amounts of carbon monoxide and carbonic acid ascertained by the extraction methods, were for the greatest part reaction gases.

The reactions occurring in the annealing tube in the system iron-carbon-oxygen are as follows:

1. $FeO + C \rightleftarrows Fe + CO$,
2. $FeO + CO \rightleftarrows Fe + CO_2$,
3. $3FeO + 5CO \rightleftarrows Fe_3C + 4\,CO_2$,
4. $3Fe + 2CO \rightleftarrows Fe_3C + CO_2$,
5. $2FeO + Fe_3C \rightleftarrows 5Fe + CO_2$,
6. $FeO + Fe_3C \rightleftarrows 4Fe + CO$.

The other systems with the components iron, carbon, manganese, oxygen or iron, carbon, silicon, oxygen, or iron, carbon, aluminum, oxygen are quaternary systems for which no equilibrium-conditions are known hitherto. The author further examined the dissociation of the carbon monoxide, formed in the reaction tube; for this purpose he annealed pure carbon monoxide in the vacuum with metallic iron, manganese, silicon and aluminum under the same

conditions and examined the progress of the reaction by measuring the pressure. These experiments included also the study of the effect of the elements manganese, silicon and aluminum used in the manufacture of steel for killing the steel.

Apart from carbon and oxygen it is possible that other elements such as sulphur, hydrogen and nitrogen participate in the reactions in the annealing tube.

To clear up the question whether the nitrogen, ascertained by the chemical analysis corresponds to that, determined by the gas examinations, steels of a different percentage of nitrogen were annealed in the vacuum at about 1100 degrees Cent. (2012 degrees Fahr.). The experiments showed that it is possible to perform the decomposition without a remainder, especially in the molten state at sufficient long annealing time.

To the valuation of the gas determination after the extraction-methods it may be said:

1. The determined amounts of carbon monoxide and carbonic acid may not be considered without ado as gases being in the steel; on the contrary it is probable that both of these gases are reaction-products; therefore it is admissible to draw a conclusion from the carbon-containing reaction gases to the percentage of oxygen in the examined steel.

2. The results with hydrogen and nitrogen may also be influenced by the reaction. The method in the molten state gives greater values of nitrogen. The nitrogen in nitrides is entirely feasible and the liquid method is to be preferred.

3. The chemical reaction or solution methods.

After producing the proof that the gases, obtained by the different methods are all formed more or less by chemical-reactions during the determination the author concludes that the different gases act as follows:

1. carbon monoxide and carbonic acid are exclusively reaction-products; their presence in iron in the dissolved state is improbable.

2. hydrogen is determined in the most reliable manner after the extraction method in the molten state.

3. nitrogen is determined in the same manner as hydrogen.

To ascerstain the gases in steel the author recommends for practical purposes the extraction method in the vacuum, whereby the determined carbon-containing gases may exclusively be considered as reaction products formed at the determination.

Solubility of carbon monoxide and carbonic acid in iron:

To examine the solubility of these gases in iron the author carried out the following experiments.

a. solubility of carbon monoxide in heated solid iron:

After distilling the material by annealing in vacuum the author examined it as to its content of carbon monoxide with the iodine method. The distilled material was then annealed at about 1150 degrees Cent. (2102 degrees Fahr.) in vacuum; after cooling, the unabsorbed gases were exhausted and the residue was anew examined for carbon monoxide. It was found that a part of the carbon monoxide had disappeared and reacted with the iron after the

equation: $$4Fe + CO \rightleftarrows Fe_3C + FeO.$$

b. solubility of carbon monoxide and carbonic acid in molten iron.

The author saturated molten iron and steel of a different percentage of carbon with 5 to 6 litres of pure, dry carbon monoxide, for 5 or 6 minutes. After casting and solidifying the samples were cut through; they showed many pores and blisters, irregularly distributed in the sample. All samples were easily malleable. The chemical examination proved that the two gases oxidized the liquid iron.

Examinations of the gases escaping at the pouring and at the solidification of steel proved that the wildness of the steel is essentially caused by carbon monoxide, being formed by the reaction of the carbon on lower oxide and oxide combinations present in the steel. This development of carbon monoxide in liquid steel lasts as long as there are lower oxides, being easily reducible still present in the steel. Therefore the thoroughness of the removal of these oxygen combinations is of greatest importance for the steel maker. Generally manganese is used as a deoxidizing medium. But a killing of the steel with manganese is impossible as the formed manganese oxide reacts on carbon after the equation:

$$FeO + Mn \rightleftarrows MnO + Fe.$$
$$MnO + C \rightleftarrows Mn + CO.$$

The carbon of the added ferromanganese reacts also on the oxygen combinations of the steel with the formation of carbon monoxide. For killing the steel only such metals may be used, of which the oxygen combinations are difficult to reduce, as silicon or aluminum.

From this it may be concluded that the carbon monoxide, formed by the reaction between the carbon and the oxygen combinations dissolved in the steel, causes the formation of blisters. Hydrogen and nitrogen play only a minor part. The fact that in blisters only hydrogen and nitrogen are generally found does not contest this interpretation, for it is proved that carbon monoxide is decomposed in contact with heated iron; by this decomposition a reduction of the pressure takes place in the blister, keeping on as long as the blister is filled with hydrogen entering in the blister by diffusion from the surrounding metal. *Abstracted by Dr. Hans Pollock.*

DISCUSSION—ON THE TRANSFORMATION OF RETAINED AUSTENITE INTO MARTENSITE BY STRESS

(Continued from Page 412)

The process of quenching was as follows:—The end of a specimen was fastened to an iron wire, 2 millimeters thick and 25 centimeters long, and placed in a salt bath at 830 degrees Cent. for 20 minutes and then cooled to 730 degrees Cent. by lowering the temperature of the bath (in our paper, this point was carelessly dropped). It was then taken out from the furnace as quickly as possible, plunged into water or oil at room temperature and was violently stirred in the liquid. Thus the structure of the quenched specimens was microscopically martensitic, no trace of troostite being present.

Messrs. Brophy and Mathews remarked that the hardness of the chromium steel used in our experiment is too low. But according to the investigation of Mr. K. Tamaru in our Institute, the hardness of quenched high

carbon steels varies from 8 to 68 Rockwell "C" according to the quantities of austenite and martensite present in the steel.[1] The hardness of the complete austenitic specimen is only 8, while that of the complete martensitic specimen is 68-C; hence it is quite plausible that by a suitable proportion of austenite and martensite, the hardness number as shown in Fig. 3 can be obtained. It may be remarked that the hardness of the quenched specimens varies very widely with annealing interval as well as the maximum temperature of heating in salt bath, and also with the rate of cooling of the specimens from the maximum to the quenching temperature.

As regards the hardness of the annealed steel, our value 25 is also plausible. By a preliminary experiment, it was found that by a different degree of annealing, the hardness 23 to 60 can be obtained, and as the annealing was effected more carefully, the effect of previous treatment disappears and approaches more and more to the mean value 25.

By a new series of experiments, we have also confirmed the above values of hardness for quenched and annealed specimens.

Dr. Mathews remarked that the difference in hardness between the annealed and quenched specimens, 25 and 14 to 33, is too small; it must be, however, remembered that the structure of the annealed specimen is pearlitic, while that of the quenched one is a mixture of martensite (hardness 68) and austenite (hardness 8). And it is a common fact that in quenched alloy steels, a large amount of austenite can be present mixed with martensite, and hence the low value of hardness can be obtained.

In our measurement of hardness, observations were made at 12 points along the specimens and their mean was taken as the final result. Hence any typographical errors for the hardness value cannot enter into our result.

As to the particulars of hammering, the following remark will be made. The specimen in the form of a rod was laid on a Kanasiki (iron block) with a plane surface and over it a thick steel plate with parallel surface was placed. The hammering was always applied on this plate; a slight permanent deformation was of course accompanied; but such a phenomenon as "atomic dispersion" or a troostitic formation cannot take place as explained above. Microscopically a troostite formation could not be confirmed.

A similar case as that quoted by O. W. Ellis is often observable in the case of steel, when a specimen which is not too small, is quenched and not violently stirred in water. Thus in a specimen quenched from a very high temperature, a small amount of troostite is found, while a specimen quenched at a lower temperature consists of a structure wholly martensitic. This abnormal phenomenon is due to the presence of water vapor formed round the specimen, the amount of which is greater in the former case than in the latter. This larger amount of vapor prevents more the loss of heat in the surrounding liquid, and thus causes a less hardening than in the latter case. This will also explain the case of Ellis.

From the explanations so far given, it will be seen that internal stress acting impulsively will change a certain amount of retained austenite into martensite, thus causing the abnormal phenomenon observed by Mathews.

[1] K. Tamaru: Sci. Rep. Tohoku Imp. Univ., 15 (1926), No. 6.

THE ENGINEERING INDEX

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Arrangements have been made with The American Society of Mechanical Engineers whereby the American Society for Steel Treating will be furnished each month with a specially prepared section of The Engineering Index. It is to include items descriptive of articles appearing in the current issues of the world's engineering and scientific press of particular interest to members of the American Society for Steel Treating. These items will be selected from the copy prepared for the annual volume of the Index published by the A. S. M. E.

In the preparation of the Index by the staff of the A. S. M. E. some 1,200 domestic and foreign technical publications received by the Engineering Societies Library (New York) are regularly searched for articles giving the results of the world's most recent engineering and scientific research, thought, and experience. From this wealth of material the A. S. S. T. will be supplied with a selective index to those articles which deal particularly with steel treating and related subjects.

Photostatic copies (white printing on a black background) of any of the articles listed may be secured through the A. S. S. T. The price of each print, up to 11 by 14 inches in size, is 25 cents. Remittances should accompany orders. A separate print is required for each page of the larger periodicals, but whenever possible two pages will be photographed together on the same print. When ordering prints, identify the article by quoting from the Index item: (1) Title of article; (2) name of periodical in which it appeared; (3) volume, number, and date of publication of periodical; and (4) page numbers.

ALLOY STEELS

MOLYBDENUM. Molybdenum Steel in Automobile Construction (Molybdänstahl im Kraftfahrzeugbau), W. Döhmer. Motorwagen, vol. 29, no. 35, Dec. 20, 1926, pp. 867-869. Influence of molybdenum steel consists mainly in heavy carbide formation, exceeding that of tungsten; effective value of molybdenum in steels; of great importance for quality of molybdenum steel is production process, and as complete deoxidation of bath as possible.

ALLOYS

ACID-RESISTING. Acid-Resisting Alloys with Nickel Basis (Säurefeste Legierungen mit Nickel als Basis), W. Rohn. Zeit. für Metallkunde, vol. 18, no. 12, Dec. 1926, pp. 387-396, 11 figs. Behavior of pure metals; chromium alloys with additions of nickel, manganese, molybdenum and carbon; alloys with nickel as main constituent; mechanical properties of nickel-chromium and iron alloys; photographic results of corrosion tests.

ACID-RESISTING. Chemically Resistant Alloys and Their Properties (Chemisch beständige Legierungen und ihre Eigenschaften), E. H. Schulz and W. Jenge. Zeit. für Metallkunde, vol. 18, no. 12, Dec. 1926, pp. 377-386, 17 figs. Based on properties of number of pure metals, conclusions are drawn as to their adaptability as bases of acid and resisting alloys; deals specifically with silicon-iron and other alloy castings, malleable chromium and chromium-nickel steels, alloys of nickel and cobalt with chromium and rust-proof coatings; deals with chemical and strength properties, and behavior at higher temperatures. Bibliography.

LIGHT. Light Alloys. Metallurgist (Supp. to Engineer), Jan. 28, 1927, pp. 1-2. Review of progress in aluminum and magnesium alloys; in regard to production of aluminum there has been only one striking forward step, development of method of refining aluminum by fusion electrolysis; development of pre-solidification processes; properties of beryllium.

ALUMINUM

ANODIC OXIDATION. The Protection of Aluminum from Corrosion. Metallurgist (Supp. to Engr.), Jan. 28, 1927, pp. 7-8. Discusses process of anodic oxidation of aluminum or its alloys; properties of anodically produced film are said to be remarkable; anodic oxidation is readily applicable to pure aluminum and to those alloys which do not contain too much copper.

CASTINGS. Impregnating Aluminum Castings With Silicate of Soda. Metal Industry (Lond.), vol. 30, no. 4, Jan. 28, 1927, pp. 109-110, 1 fig. Successful method of treating aluminum castings for porosity if used on gasoline or oil lines by use of silicate of soda; apparatus is composed primarily of two steel cylindrical shaped bottles, one known as impregnating bottle, other known as feeder bottle.

METALLURGICAL DEVELOPMENTS. Aluminum and Its Alloys, H. W. Clarke. Metal Industry (Lond.), vol. 30, no. 1, Jan. 7, 1927, pp. 21-23. Intensive recent research in aluminum; cast alloys of aluminum; duralumin type of alloys; wrought aluminum alloys; duralumin in aircraft construction.

ALUMINUM ALLOYS

ALUMINUM-COPPER. Light Aluminum-Copper Alloys. Foundry Trade Jl., vol. 35, no. 544, Jan. 20, 1927, p. 54. Methods of making up 92:8 aluminum-copper alloy in foundries for casting purposes; defects; proportion of aluminum alloys in demand for other castings, such as aluminum-magnesium, aluminum-zinc, aluminum-copper-tin, or aluminum-copper-manganese, is small compared with that for castings of 92 per cent aluminum and 8 per cent copper alloy.

ALUMINUM-GERMANIUM. Alloys of Aluminum with Germanium (Das Diagram Germanium-Aluminum). W. Kroll, Metall u. Erz., vol. 23, no. 24, Dec. 2, 1926, pp. 682-685, 4 figs. Contains two articles on investigation of alloys of germanium with alu-

minum, and also replacement of silicon by germanium in alloys of duralumin type; presents equilibrium diagram of aluminum-germanium system, which is simple eutectiferous one, closely resembling silicon-aluminum series; melting point of eutectic is 233 degrees Cent. below melting point of aluminum; it may prove useful as solder; study of Brinell hardness of alloys, showing that germanium hardens aluminum much more rapidly than does silicon; in alloys of duralumin type, germanium can replace silicon in formation of silicide which confers age-hardening properties on resulting alloys; small additions of germanium improve alloys of duralumin, lautal and aludur types. See translated abstract in Metallurgist (Supp. to Engr.) Jan. 28, 1927, pp. 6-7.

ALUMINUM-MANGANESE. Equilibrium Relations in Aluminum-Manganese Alloys of High Purity, E. H. Dix, Jr., and W. D. Keith. Am. Inst. Min. & Met. Engrs.—Trans., no. 1633-E, Feb. 1927, 19 pp., 12 figs. Explanation of phenomenon encountered in aluminum-manganese system, namely, that undercooling during chill-casting has produced extremely fine eutectic structure so that no evidence of finely divided particles of two phases can be obtained microscopically in chill-cast specimen; this is supported by fact that hypoeutectic alloys on annealing only show particles in areas commonly forming eutectic network; that this is a very unusual system is shown by fact that alloys cooled slowly at rate of approximately 100 degrees Cent. per hour.

ALUMINUM-SILICON. Aluminium-Silicon Alloys. Metallurgist (Supp. to Engr.), Jan. 28, 1927, pp. 8-14, 12 figs. Review of three papers dealing with constitution, structure and properties of these alloys, namely, by Gwyer and Phillips (with appendix by Stockdale), by Grogan and by Otani, respectively; also review of investigation by Petit, published in Revue de Métallurgie.

AUTOMOBILE. Light Alloys in the Automobile. Am. Metal Market, vol. 34, no. 32, Feb. 15, 1927, pp. 3-6 and 15, 28 figs. Indicates directions in which light aluminum alloys are used to advantage in commercial production to achieve not only weight reduction but higher efficiency and better performance; deals with housings, pistons, cylinders, connecting rods, axles and wheels, and bodywork. Reprinted by permission of British Aluminum Co.

CASTING. Still Casting of Metals, P. H. G. Durville. Am. Inst. Min. & Met. Engrs.—Trans., no. 1651-E, Feb. 1927, 6 pp. Pure aluminum, or alloy containing small proportion of aluminum, can be melted without flux except for layer of charcoal, because film of aluminum oxide and metal forms at surface of melted aluminum; although very thin, this film is air-proof, and it prevents metal underneath from oxidizing; this oxidized film does not move easily on account of its toughness and high surface tension; "still casting" as exemplified in two methods, permits of production without great expense and trouble, of alloys containing aluminum.

CASTINGS. Light Alloy Castings in Marine Engineering, G. Mortimer. Metallurgist (Supp. to Engineer), Jan. 28, 1927, pp. 2-6, 4 figs. Early experiences with aluminum alloys; development of silicon alloys, and their properties; specifications of Brit. Eng. Standards Assn. for light casting alloys; requirements of U. S. Navy Department for castings and sea-water corrosion; protective coatings; necessity of light weight in all forms of transport.

LAUTAL. Lautal in Ship Construction. Metal Industry (Lond.), vol. 30, no. 5, Feb. 4, 1927, p. 141. Its successful use in rotors of new rotor ship, Barbara.

SILUMIN. Silumin and its Structure, B. Otani. Tohoku Imperial Univ.—Science Reports, vol. 15, no. 5, Nov. 1926, pp. 679-719, 13 figs. Presents theory explaining occurrence of fine structure from results which have been obtained from experiments carried out by author; binary diagram of aluminum and silicon system; process of producing silumin; different fluxes and their modifying action; cooling velocity and structure of aluminum and silicon alloys; eutectic crystallization of aluminum and silicon alloys and their electric resistances. (In English.)

ALUMINUM BRONZE

CASTING. Some Facts About Aluminum Bronze, W. Baunard. Brass World, vol. 23, no. 1, Jan. 1927, pp. 3-5. Practical hints to aluminum foundries concerning best methods of obtaining satisfactory castings; difficulties which face beginner, when attempting fine work.

AUTOGENOUS WELDING

COPPER FIREBOXES. Autogenous Welding of Copper Fireboxes (Das autogene Schweissen von kupfernen Feuerbüchsen), Prinz. Organ für die Fortschritte des Eisenbahnwesens, vol. 81, no. 22, Nov. 30, 1926, pp. 458-461, 12 figs. Results of tests carried out in Munich; economy of autogenous welding of fireboxes in production, operation and maintenance; cost data; testing of welds.

BLAST FURNACES

AIR HEATERS. Theory of Air Heaters (Die Theorie des Winderhitzers), W. Nusselt. V. D. I. Zeit., vol. 71, no. 3, Jan. 15, 1927, pp. 85-91, 8 figs. Formulas are developed for calculation of temperature in air heaters for five different simplified cases.

ALKALI CYANIDES IN. Occurrence, Distribution and Significance of Alkali Cyanides in the Iron Blast Furnace, S. P. Kinney and E. W. Guernsey. U. S. Bur. of Mines, technical paper 390, 37 pp., 12 figs. Previous work is summarized; method for determining alkali-cyanide content of gases at different points in interior of blast furnace has been developed and values for one furnace have been determined; calculations indicate that concentration of alkali cyanide would not be greatly lowered by withdrawing part of gas for recovery of cyanides; it seems unlikely that operation of blast furnace would be adversely affected by withdrawal of small part of gas for recovery of cyanides; amount of alakali cyanide recoverable in this way would be commercially significant.

CHARGING. Electric Charging of Blast Furnaces (Monte-charges électriques pour hauts-fourneaux), R. Baudoin. Electricien, vol. 58, no. 1411, Jan. 1, 1927, pp. 2-8, 13 figs. Deals with four classes of chargers: (1) vertical individual, (2) American inclined system, (3) Stahler, Secomet and similar systems, and (4) vertical collective system; control of chargers.

DEVELOPMENTS. Progress in the Blast Furnace Field, F. H. Wilcox. Blast Furnace

& Steel Plant, vol. 15, no. 1, Jan. 1927, pp. 19-20. Outlines progress made during past year in improving practice and points out trend for further betterment.

EFFICIENCY. Specific Efficiency of the Blast Furnace. Mining & Met., vol. 8, no. 242, Feb. 1927, pp. 55-60. Discussion of paper by R. Franchot published in Sept. issue of same Journal.

SCRAP IN BURDEN. Iron and Steel Scrap in Blast-Furnace Burdens. Mining & Met., vol. 8, no. 241, Jan. 1927, pp. 20-23. Discusses effect of scrap in pig iron made from it; effect of scrap on blast furnace; and question as to whether shaft has excess heat available for melting. Discussion of paper by W. C. McKee in Oct. 1926 issue of same journal.

TUYERE CONNECTION. Blast-Furnace Tuyere Connection. Iron & Coal Trades Rev., vol. 114, no. 3071, Jan. 7, 1927, pp. 5, 3 figs. Describes connection developed by H. Crowe, essential feature of which is improved form of constructing goose neck, which has spherical joint at its upper end so arranged as to possess ample movement in every direction, and fitted with one set of tension gear whose force acts in one direction only, allowing for expansion of all parts.

WEIRTON, W. VA. New Stack Ranks Among Largest, G. F. Tegan. Iron Age, vol. 119, no. 4, Jan. 27, 1927, pp. 278-279, 1 fig. New blast furnace of Weirton Steel Co. can produce 1000 tons daily; layout permits direct pouring into 65-ton ladles, which usually go to mixer in open-hearth plant.

BOILER PLATE

MANUFACTURE. The Making of Boiler plate, J. A. Shannon. Boiler Maker, vol. 27, no. 1, Jan. 1927, pp. 11-12. Open-hearth process most commonly used in United States; making of ingot; life of open-hearth furnace; drawing iron; stripping mold and rolling plates.

BOILERS

CRACKS AND CORROSION. Cracks and Corrosion in Boiler Parts (Rissbildungen und Anfressungen an Dampfkesselelementen), F. Körber and A. Pomp. Zeit. des Bayerischen Revisions-Vereins, vol. 30, nos. 23 and 24, Dec. 15 and 31, 1926, pp. 279-285 and 295-301, 29 figs. Investigation with aid of Fry etching process of water tubes, boiler heads with and without manholes, etc.; relationship between cracks and corrosion; process of corrosion and crack formation; influence of quality of material, boiler construction and operating conditions on crack formation and corrosion.

BRASS

CAST, TRANSITION POINT. A Study of the 470 Deg. Cent. Transition Point in Cast 60:40 Brass, F. H. Clark. Am. Inst. Min. & Met. Engrs.—Trans., no. 1637-E, Feb. 1927, 18 pp., 51 figs. Comparison of rolled 60:40 brass and cast 60:40 brass gives same results when they are heated up into beta range, quenched in iced brine, and reheated at varying temperatures; at 200 degrees Cent. fine sorbitic structure appears; above 450 degrees Cent. both alloys contain annealing twins; drastic quenching in iced brine, together with change in volume, due to breaking down of beta into fine, sorbitic structure, has distorted space lattice and produced strain gradient. Bibliography

HOT ROLLING. Modern Developments in the Hot Rolling of Brass and Copper in Germany. Metal Industry (Lond.), vol. 30, no. 1, Jan. 7, 1927, pp. 43-45, 1 fig. Method has lately been largely adopted in Germany by which practically any brass alloys can be hot-rolled; method requires that slabs to be rolled should be cast in specially designed iron molds and rolled in three-high rolling mill at rolling speed of about 7 feet per second.

CAR WHEELS

CHILLED-IRON. Chilled-Iron Wheels in America and at the Railway Engineering Congress in Berlin (Das Hartgussrad in Amerika und auf der Eisenbahntechnischen Tagung in Berlin), E. Rüker. Dinglers Polytechnisches Jl., vol. 107, no. 22, Nov. 1926, pp. 249-256, 5 figs. Calls attention to wide spread use of chilled wheels in United States, and attitude of German engineers as expressed at Railway Engineering Congress held in Berlin in 1924, with regard to safety, life, abrasive resistance of material, profile hardness, etc.

CAST IRON

ALLOYING UNIT. Alloying Unit for Gray Iron Plants, H. P. Parrock. Iron Age, vol. 119, no. 3, Jan. 20, 1927, pp. 203-205. Suggests practical method of improving gray iron foundry trade by increasing range of useful irons by use of alloys; proposes use of open-hearth furnace of suitable size and type, conveniently placed to take hot metal, with small complementary electric furnace for melting alloys; this melting and alloying unit would constitute an intermediary step between blast furnace and pig machine.

AUTOMOTIVE INDUSTRY. Cast Iron Relating Particularly to the Automotive Industry, E. J. Lowry. Am. Metal Market, vol. 34, no. 32, Feb. 15, 1927, pp. 13-15. It is concluded that misinformation regarding cast irons has caused unfortunate circumstances to surround its application; there is too little authentic information regarding elements of cast iron; Brinell test does not actually indicate hardness, combined carbon, wear or machinability, but quality raw materials affect these factors; expansion of raw materials affect resulting product; wear and machinability are induced by quality materials.

COKE, EFFECT OF. Coke Causes Leaky Castings, J. A. Murphy. Foundry, vol. 55, no. 2, Jan. 15, 1927, pp. 63-64. Theories tried in experimental cupola and in full-sized units proved that soft coke is responsible for coarse open-grain iron.

CONSTITUTION. The Constitution of Steel and Cast Iron, F. T. Sisco. Am. Soc. for Steel Treating—Trans., vol. 11, no. 2, Feb. 1927, pp. 284-296, 8 figs. Discusses constitution of iron-carbon alloys containing 1.70 to 4.30 per cent carbon; they are known as hypoeutectic cast irons and are made up of eutectic of saturated austenite and cementite; and excess constituent, saturated autenite; describes constitutional changes in this series of alloys when cooled from molten state to atmospheric temperature.

DESULPHURIZING. Desuiphurization of Cast Iron. Brit. Cast Iron Research Assn.—Bul., no. 15, Jan. 1927, pp. 24-25. Bibliography of more important articles published during last few years; patent specifications.

DEVELOPMENTS, 1926. Cast Iron in 1926, J. E. Fletcher. Brit. Cast Iron Research Assn.—Bul., no. 15, Jan. 1927, pp. 14-24. Influence of scrap on blast-furnace product; variations in composition and fracture; iron from "all-mine" burdens; importance of low total carbon content in foundry iron; substitutes for low carbon pig iron; production of stronger irons in cupola. Paper read before Staffordshire Iron & Steel Inst.

DIFFUSION IN. Diffusion in Metallic State with Special Reference to Sulphur and Phosphorus in Cast Iron (Die Diffusion im metallischen Zustand, insbesondere die des Schwefels und Phosphor im Gusseisen), F. Roll. Giesserei, vol. 14, no. 1, Jan. 1, 1927, pp. 1-7, 15 figs. Points out that in cast iron diffusion plays important role, causing continuous changes in mass corresponding to temperature.

ELECTRICAL RESISTANCE. Changes in the Specific Electrical Resistance of Cast Iron Due to Heating and Cooling. Brit. Cast Iron Research Assn.—Bul., no. 15, Jan. 1927, pp. 26-28, 2 figs. Influence of heat; where specific electrical resistance is important, for high specific resistance cast iron should be hard, while irons of low specific resistance should be soft, preferably malleableized; for irons, specific electrical resistance of which must not change on heating, metal should be heat resisting type, which will give iron of comparatively high specific resistance; malleable irons cannot be used reasonably safely near to or beyond region of critical point.

HIGH-GRADE. High-Grade Gray Cast Iron and its Production (Hochwertiger Grauguss und seine Herstellung), Klingenstein. Giesserei-Zeitung, vol. 23, no. 24, Dec. 15, 1926, pp. 680-686, 26 figs. Classification of gray cast iron according to its tensile strength; relations of mechanical properties of gray iron and their analyses; Lanz-Perlit-Maurer diagram; Greiner-Klingenstein diagram; desulphurization; Thyssen-Emmel process; Corsalli process; Wüst furnace; graphite removal in gray iron.

IMPROVEMENT. Old Methods in New Form for Improvement of Cast Iron (Alte Verfahren der Gussveredelung in neuer Auflage), A. Lissner. Giesserei Zeitung, vol. 23, no. 24, Dec. 15, 1926, pp. 678-679. Gives proof that some of modern improvement processes are not new discoveries, but were formerly known and since forgotten; shaking and jolting of cast iron was developed by H. Storek, 23 years ago.

PEARLITIC STRUCTURE. Pearlitic Structure of Cast Iron. Foundry Trade Jl., vol. 35, no. 542, Jan. 6, 1927, p. 7. Review of paper by J. G. Pearce.

SHEAR TEST. The Strength of Cast Iron Based on Shear Test (Beurteilung der Festigkeit von Gusseisen nach dem Scheversuch), H. Fev. Stahl u. Eisen, vol. 46, no. 51, Dec. 23, 1926, pp. 1829-1833, 13 figs. Results of tests carried out by association of German Foundrymen.

CASTINGS

DEOXIDATION. Deoxidation Misleading Term, C. Vickers. Foundry, vol. 55, no. 2, Jan. 15, 1927, pp. 55-57. Points out that important feature in melting nonferrous metal is ability to determine whether molten metal should be oxidized or deoxidized.

COKE-OVEN GAS

STEEL INDUSTRY. The Uses of Coke-Oven Gas in the Steel Industry, L. M. Wilson. Fuel, vol. 6, no. 1, Jan. 1927, pp. 29-36. Use of coke-oven gas alone in furnaces; coke-oven gas mixed with producer-gas in melting furnaces; use of coke-oven gas with blast-furnace gas.

COPPER

CORROSION. Effect of Oxygen Concentration on the Corrosion of Copper by Non-Oxidizing Acids, R. P. Russell and A. White. Indus. & Eng. Chem., vol. 19, no. 1, Jan. 1927, pp. 116-118, 7 figs. Quantitative study showing that corrosion in dilute sulphuric, hydrochloric, and acetic acids is proportional to concentration of dissolved oxygen; corrosion by sulphuric and acetic acids is much less than by hydrochloric acid.

PHOSPHORIZED. Some Comparative Properties of Tough Pitch and Phosphorized Copper, W. R. Webster, J. L. Christie and R. S. Pratt. Am. Inst. Min. & Met. Engrs.—Trans., no. 1643-E, Feb. 1927, 17 pp., 8 figs. Determination of relative effects of cold drawing upon two kinds of copper in question.

COPPER ALLOYS

ALLOYS, EFFECT OF. Influence of Zinc, Tin, Aluminum and Magnesium on Copper Containing Cuprous Oxide (Ueber die Einwirkung von Zink, Zinn, Aluminium und Magnesium auf kupferoxydulhaltiges Kupfer), O. Bauer and H. Arndt. Giesserei-Zeitung, vol. 23, no. 24, Dec. 15, 1926, pp. 671-677, 21 figs., partly on supp. plates. Review of previous work on subject; diffusion and solution phenomena; behavior of cuprous oxide; experimental results in graphic form; application of results to foundry practice.

BERYLLIUM-COPPER. Beryllium-Copper Alloys, W. H. Basset. Am. Inst. Min. & Met. Engrs.—Trans., no. 1634-E, Feb. 1927, 15 pp., 27 figs. Investigation to determine under mill conditions behavior of copper when alloyed with beryllium and when other metals were added to such alloys; it seems probable that, with beryllium at commercial prices, its alloys might be used for springs, stronger wires, and high-strength conductors.

COPPER-SILICON. Merit in Copper-Silicon Alloys, M. G. Corson. Iron Age, vol. 119, no. 5, Feb. 3, 1927, pp. 353-356, 9 figs. Comparative cheapness, high strength, ease of working, and resistance to corrosion are salient features; problem of resistance to corrosion; chemical influence of silicon; silicon-copper alloys for castings.

CORSON ALLOYS. Copper Hardened by New Method, M. G. Corson. Iron Age, vol. 119, no. 6, Feb. 10, 1927, pp. 421-424, 9 figs. Besides high copper-silicon alloys there has recently been discovered group of 4 series of ternary alloys, known as Corson alloys, each containing relatively small amounts of silicon in addition to much larger amounts of chromium, iron, cobalt or nickel; all 4 series form natural class of alloys, which are amenable to heat treatment in a way that makes them appear to be counterpart of duralumin.

ELECTRIC CONDUCTORS, FOR. Improving Electric Conductor Alloys, M. G. Corson. Elec. World, vol. 89, no. 3, Jan. 15, 1927, pp. 137-139. Requirements of conductors; characteristics of alloys of aluminum and

copper; new alloys of copper possess great strength and wear resistance.

VISCOSITY AT ELEVATED TEMPERATURE. Study of Viscosity at High Temperature (Suite à l'étude de la viscosité à température élevée), J. Cournott and R. Pages. Revue de Métallurgie, no. 12, Dec. 1926, pp. 701-708, 7 figs. Results of series of tests on copper and its alloys.

CORROSION

LIGHT-METAL ALLOYS. Use of Mylius Corrosion Test on Different Light-Metal Alloys (Die Anwendung der oxydischen Kochsalzprobe nach Mylius auf verschiedene Leichtmetall-Legierungen), B. Rackwitz and E. K. O. Schmidt. Korrosion u. Metallschutz, vol. 2, nos. 11/12, Nov.-Dec. 1926, pp. 257-261, 2 figs. Investigation of Mylius corrosion test, more particularly in its application to wrought light alloys, such as duralumin, lautal, and to magnesium alloys; authors apply test reagent to one side only of specimen of sheet metal of such form that it can be used for tensile test; they find that reagent departs from their ideal of corrosion-testing medium in several ways. See translated abstract in Metallurgist (Supp. to Engr.), Jan. 28, 1927, p. 16.

RESEARCH. Corrosion Research of the German State Chemical and Technical Institute (Korrosionsforschungen der Chemisch-Technischen Reichsanstalt), J. Hausen. Metall u. Erz, vol. 23, no. 23, Dec. 1, 1926, pp. 649-652. Protection of metals; status of present knowledge of corrosion; review of work of Chemisch-Technischer Reichsanstalt.

CRANES

STEEL MILLS. General Specifications for Electric Overhead Traveling Cranes—Heavy Duty Steel Mill Service. Iron & Steel Engr., vol. 4, no. 1, Jan. 1927, pp. 21-25. Specifications applying to heavy-duty steel-mill cranes, and as far as practical, to cranes for special service such as stripping ingots, charging ingots into and drawing them out of soaking pits, ore handling, charging open-hearth furnaces, etc.

CRYSTALS

IRON. Iron Single Crystals (Eisenein-kristalle), W. Gerlach. Zeit. für Physik, vol. 39, no. 5-6, Oct. 1926, pp. 327-331, 1 fig. Previous experimental results are discussed, together with those of Geiss and van Liempt; by cold working, specific resistance increases greatly, but its temperature coefficient diminishes; on heating, iron becomes normal again; cold-working increases strength of single crystal, but not of rod consisting of many fine crystals, yet both show great increase in "magnetic hardness"; heating produces magnetic restoration.

CUTTING METALS

CAST IRON. Metal Cutting with Cylindrical Cutters (Die Metallbearbeitung mittels Walzenfräser). F. Beckh. Maschinenbau, vol. 5, no. 24, Dec. 16, 1926, pp. 1119-1121, 9 figs. Results of tests, to investigate conditions in cutting of cast iron; results are utilized to determine most economical working speed.

COAL GAS FOR. Gas for Cutting, A. Krebs. Gas Industry, vol. 27, no. 2, Feb. 1927, pp. 45-46, 1 fig. Results of actual experience with city gas and ordinary heating torches.

UNDER-WATER. Cutting Metals Under-Water, L. F. Hagglund. Acetylene Jl., vol. 28, no. 7, Jan. 1927, pp. 325-327 and 357, 7 figs. Describes combination of electric arc with oxygen; depth of water does not affect arc and increase in depth simply means increase in pressure at which oxygen gas is supplied; metal-cutting apparatus consists of generating unit, switchboard and resistance, supply of oxygen, oxygen regulator and hose, and double-conductor hose through which both oxygen and electricity are carried to torch; application to salvage marine "S-48," and other applications.

CUTTING TOOLS

ALUMINUM ALLOYS, FOR. Turning Tool for Aluminum Alloys. Eng. Progress, vol. 8, no. 1, Jan. 1927, p. 6, 1 fig. New cutting tool which is really combination of two tools, namely roughing and finishing tool; results of tests on alloy containing 78 per cent aluminum and 22 per cent silicon.

DIE CASTING

MOLDS FOR. Making Molds for Die Casting, J. H. Smit. Machy. (N. Y.), vol. 33, no. 6, Feb. 1927, pp. 441-444, 2 figs. Preparing die blocks; machining die cavities; matching cavities; making cores; factors to be considered in making molds for die casting; life of molds; causes of cracking; scored mold cavities.

DURALUMIN

WELDING. Duralumin Welding, W. Nelson. Aviation, vol. 22, no. 3, Jan. 17, 1927, pp. 130-132, 3 figs. Possibilities and methods of gas welding; fluxes used; welding sheet metal.

ELECTRIC FURNACES

INDUCTION. Induction Furnace Finds Wider Use, E. C. Kreutzberg. Iron Trade Rev., vol. 80, no. 2, Jan. 13, 1927, pp. 139-141, 6 figs. Describes furnace in use at new plant of Ajax Co. for melting nickel steel; melting equipment is tilting frame which holds crucible in induction coil, latter forming nest for crucible. See also description in Metal Industry (N. Y.), vol. 25, no. 1, Jan 1927, pp. 4-5, 7 figs.

MELTING. Electric Furnaces for Melting Metal. Blast Furnace & Steel Plant, vol. 15, no. 1, Jan. 1927, pp. 34-36, 1 fig. Practice in melting both iron and steel; methods of control and various furnace types.

MELTING. Electric Melting of Gray Iron Saves $30 per Ton, J. L. Faden. Elec. World, vol. 89, no. 3, Jan. 15, 1927, pp. 139-140, 1 fig. Castings produced at Century Electric Co.'s plant, St. Louis, with electric heat; Moore 'Lectromelt furnace of ½-ton rated capacity was installed; service reliability and cost data significantly in favor of electricity.

REVOLVING-RETORT. Rockwell Electric Revolving-Retort Furnaces. Am. Mach., vol. 66, no. 2, Jan. 13, 1927, p. 75, 1 fig. Machine is designed especially for annealing nonferrous metal parts and has capacity ranging from 1500 to 2000 pounds per hour, according to weight, thickness and size of individual pieces.

ELECTRIC WELDING

CAST IRON. Electric Welding (Elektrische Schweisstechnik), P. Schimpke. Giesserei, vol. 14, no. 3, Jan. 15, 1927, pp. 33-37, 15 figs. Review of principles of modern electric welding with special regard to welding of cast iron; resistance in arc welding; cold and hot welding of cast iron; electric cutting.

RAILWAY REPAIR SHOPS. New Electric Welding Equipment in Railway Repair Shop at Ingolstadt, Germany (Die neue Werkstätte für Elektroschweissung beim Eisenbahnausbesserungswerk Ingolstadt), Grimm. Organ für die Fortschritte des Eisenbahnwesens, vol. 81, no. 22, Nov. 30, 1926, pp. 454-457, 4 figs. Equipment and methods in new department for electric welding.

ELECTRIC WELDING, ARC

ARC SPUTTERING. Theory of Arc Sputtering, J. B. Green. Welding Engr., vol. 12, no. 1, Jan. 1927, pp. 29-31, 1 fig. Silent and hissing arcs; chemical changes in deposit metal; and in arc atmosphere; arcs in inert cases; protective electrode coating; development of theory of sputtering and its applications.

BUILDING CONSTRUCTION. Designing the Sharon Building for Arc-Welding, G. D. Fish. Eng. News-Rec., vol. 98, no. 3, Jan. 20, 1927, pp. 102-106, 6 figs. Successful construction of five-story factory building of Westinghouse Elec. & Mfg. Co. required many departures from usual practice; continuity of beams utilized to secure economy.

STRUCTURAL STEEL. Arc-Welded 5-Story Building Nears Completion. Iron Trade Rev., vol. 80, no. 2, Jan. 13, 1927, pp. 136-138, 6 figs. Describes welding of 5-story structure at Sharon, Pa.

ELECTRIC WELDING, RESISTANCE

TESTING WELDS. Testing Resistance Welds, J. W. Meadowcroft. Welding Engr., vol. 12, no. 1, Jan. 1927, pp. 41-42, 3 figs. Points out that microscope will reveal quality of joints in butt, flash and spot welding.

ELECTROCHEMISTRY

PROGRESS. Recent Advances in Electrochemistry, C. G. Fink. Mining & Met., vol. 8, no. 242, Feb. 1927, pp. 52-55, 4 figs. Increasing demand for electric furnaces calls for better refractories; methods for making purer metals; insoluble anodes and new methods of overcoming corrosion.

FERROSILICON

SILICON DETERMINATION IN. Rapid Determination of Silicon in 8 to 17 Per Cent Ferrosilicons, G. T. Dougherty. Indus. & Eng. Chem., vol. 19, no. 1, Jan. 1927, pp. 165-167. Degree of decomposition was determined by new method and also by existing English methods.

FILES

MANUFACTURE. The Manufacture of Files at Templeborough Works, Sheffield, J. W. Walker. Engineer, vol. 142, nos. 3698, 3699, and 3700, Nov. 26, Dec. 3, and 10, 1926, pp. 578-579, 606-608, and 629-631, 30 figs. partly on p. 582. Describes various materials and processes employed in file making; forging and heating; tanging, rolling, boss work and semi-automatic processes; annealing and straightening; furnaces, temperature, decarbonization; hardening, scouring, sand blasting and testing.

FORGING

BRITISH AND AMERICAN PRACTICE. British and American Practice in the Working of Hot and Cold Metals, F. W. Spencer. Metal Industry (Lond.), vol. 30, no. 5, Feb. 4, 1927, pp. 139-140. Drop hammer; steam and board hammers; nonferrous forgings; steel forgings; forging cold.

FORGINGS

BRASS. Brass Forgings, O. J. Berger. Mech. World, vol. 81, no. 2090, Jan. 21, 1927, pp. 50-51. Gives reasons for replacing brass castings with forgings; comparison of machining costs; finish and strength of forgings; equipment for forging shop; preparing blank; dies for hot-pressed parts and for drop-steam hammers; importance of correct heating.

FOUNDING

SIMPLIFICATION. Simplifying Foundry Work, A. Dogan. Foundry Trade Jl., vol. 35, no. 544, Jan. 20, 1927, pp. 55-58, 4 figs. Principles of molding; principles of solidification and equilibrium diagrams; bronzes; effect of design upon crystallization; effect of casting temperature on crystallization and solidification; structures of industrial alloys; brasses; effect of changes of composition.

FOUNDRIES

PROGRESS. Recent Foundry Progress (Les progrès récents en fonderie), J. Cournot and J. Galibourg. Technique Moderne, vol. 18, no. 23, Dec. 1, 1926, pp. 729-736, 15 figs. Review of developments with regard to employment of new casting processes, and by improvement in materials and methods of testing and control.

SCIENCE APPLICATIONS IN. Applying Science in the Foundry, C. H. Ridsdale. Foundry Trade Jl., vol. 34, nos. 537, 538 and 539, Dec. 2, 9 and 16, 1926, pp. 475-476, 499-504 and 519-522, 24 figs. Difficulties of modern scientific language; cast iron; proximate and structural compositions; phosphorus iron eutectic; iron silicide and silicoferrite; provision of fundamental data; micrographic work; modern progress; pearlitic castings; concludes that general comprehension and application of scientific facts and results of research would come about much more quickly and easily if they were presented simply and clearly in language which everyone could understand, and technical societies might do much to bring this about.

FURNACES

SHAFT. Theory of Heating (Sur la théorie du chauffage), H. LeChatelier. Revue de Metallurgie, no. 11, Nov. 1926, pp. 629-648, 10 figs. Deals with theory of heating in shaft furnaces, including lime kilns, blast furnaces and cupolas; disturbing influences; it is shown that proper functioning of shaft furnaces depend on two factors: (1) calculation of exchange of heat, and (2) inequality of speed of circulation of different currents, particularly gas.

FURNACES, HEAT-TREATING

GAS-FIRED. Heat Treatment with Gas (Les traitements thermiques au gaz), J. B. Brodin. Outillage, vol. 370, no. 5, May 1926, pp. 828-831, 4 figs. Discusses properties of illuminating gas for heat treating; describes types of gas burners and Tourbillon furnace based on heat compression; surface combustion and maximum of radiated heat. See also Jl. des Usines a Gaz, vol. 50, nos. 11 and 14, June 5 and July 20, 1926, pp. 211-215 and 278-280, 7 figs.

FURNACES, HEATING

INGOT-HEATING. A New Furnace for Rolling Mills (Ein neuer Walzwerksofen, Bauart Bohler), F. Hartmann. Stahl u. Eisen, vol. 47, no. 2, Jan. 13, 1927, pp. 57-61, 4 figs. Details of Bohler ingot-heating furnace, which is shaft furnace in which charge travels in vertical direction from bottom to top of furnace; heating is effected from top towards bottom, so that ingots on top are hottest, whereas lower rows remain comparatively cold and afford natural protection against superheating of charging equipment; advantages of vertical ingot-heating over other rolling-mill furnaces include considerable saving in fuel, less space requirement, lower initial cost, etc.

FURNACES, METALLURGICAL

NONFERROUS METALS, FOR. Modern Metallurgical Furnaces for Nonferrous Metals (Les fours modernes de la metallurgie des métaux autres que le fer), M. Fourment. Technique Moderne, vol. 18, no. 23, Dec. 1, 1926, pp. 715-722, 31 figs. Developments in roasting, melting and electric furnace.

HEAT TREATMENT

DEVELOPMENTS. Recent Developments in Heat-Treating Equipment (Les progrès récents réalisés dans l'equipement des ateliers de traitement thermique), J. Galibourg and J. Cournot. Technique Moderne, vol. 18, no. 23, Dec. 1, 1926, pp. 737-750, 34 figs. Deals with new processes, including cementation by carbon, by aluminum, and by nitrogen; hardening; heat treatment of alloys of lead and antimony; brazing and soldering; gas and electric furnaces; automatic furnaces; apparatus for cementation and hardening; methods and equipment of control.

IMPACT TESTING

NOTCHED-BAR TESTS. The Law of Similarity and the Notch-Bar Test (Das Aehnlichkeitsgesetz bei der Kerbschlagprobe), R. Mailänder. Kruppsche Monatschrifte, vol. 7, Dec. 1926, pp. 217-222, 9 figs. Results of tests show that if dimensions of notch are proportional to dimensions of cross section, specific impact energy increases with increasing size of specimens; rule given by Moser that specific impact energy is independent of size of sample when these samples have similar fracture profile and uniformly large notches, holds true only to limited degree; for tests with severing fractures, it does not hold true.

REPEATED IMPACT. Study of Repeated Impact Tests (Contribution à l'étude des essais de chocs répétés), E. Duchemin. Revue de Métallurgie, no. 12, Dec. 1926, pp. 718-722, 3 figs. Influence of shape of notch; results of tests show that pointed notch and round notch have different effects on formation of crack, which is proportionally more rapid with pointed notch for equal number of blows; fatigue of metal under action of repeated blows (about 5000) does not seem to diminish with action of tempering.

IRON

ALUMINUM DEPOSITION. Metal Coating with Aluminum (Das Alumetierverfahren), R. Hopfelt. Wärme, vol. 49, no. 52, Dec. 24, 1926, pp. 899-900, 2 figs. Points out possibility of annealing aluminum wire to 2000 degrees Cent.; different methods of protecting iron against high temperatures by means of aluminum coating; application of metal-spray process; describes process developed by author called Alumetier process, with which metal in cold or slightly heated condition receives deposition of aluminum in any desired thickness; after drying of coated metal, it is annealed in furnace at temperature of 800 degrees Cent., causing aluminum layer to penetrate into iron and iron into aluminum layer; process can also be employed for cast iron.

CEMENTATION. Cementation of Iron by Silicon Chloride (La cémentation du fer par le chlorure de silicium), A. Sanfourche. Académie des sciences—Comptes rendus, vol. 183, no. 19, Nov. 8, 1926, pp. 791-793. Cementation without solid contact was brought about by action of silicon chloride on compact iron in form of cylindrical bars of soft iron.

DESULPHURIZING. Desulphurization Action of Fluorine Compounds on Molten Iron (Die entschwefelnde Wirkung von Fluorverbindungen auf geschmolzenes Eisen), E. Wilke-Dörfurt and H. Buchholz. Stahl u. Eisen, vol. 46, no. 51, Dec. 23, 1926, pp. 1817-1820, 1 fig. From system iron-plus-slag melted in crucible furnace, sulphur is removed by addition of fluorspar; desulphurization can be increased considerably when, in place of fluorspar, other more reactive fluorine compounds are used, with condition, however, that fluoride reacts with iron bath.

DIRECT PRODUCTION. Making Iron Without Coke at Minnesota Mines, E. W. Davis. Iron Trade Rev., vol. 80, nos. 2 and 3, Jan. 13 and 20, 1927, pp. 133-135 and 144; and 197-200, 5 figs. Results of experiments at School of Mines Experiment station, Univ. of Minnesota; describes two-step process doing away with use of coke and using minimum of coal for direct reduction; while resulting product has been called pig iron, it is not pig iron as produced in blast furnace, because it contains only small fraction of per cent of silicon, perhaps 2 per cent carbon, and with sulphur and phosphorus both below 0.04 per cent; it is neither pig iron nor steel, within customary definitions.

OXIDATION. Mechanism of Oxidation of Iron With Steam, Air, and Carbon Dioxide at High Temperatures (Ueber den Mechanismus der Oxydation des Eisens mit Wasserdampf, Luft und Kohlensäure bei hohen Temperaturen), P. P. Fedotjeff. Zeit. für anorganische und allgemeine Chemie, vol. 157, no. 1-3, 1926, pp. 165-172. Product of oxidation of iron by steam at 1000 to 1100 deg. changes continuously in composition from ferrous oxide to ferrosoferric oxide, although at any given time only one solid phase is present; it thus seems that both isomorphous mixtures and solid solutions of oxides must be formed.

IRON ALLOYS

IRON-CARBON. Evidences Concerning the Location of the Carbon Atom in Boydenite, H. A. Schwartz. Am. Soc. for Steel Treating—Trans., vol. 11, no. 2, Feb. 1927, pp. 277-283. Name boydenite was coined some years ago by author to describe solid solution of stable iron-carbon system; attempt is made to further support author's opinion that solid solutions of carbon in iron in equilibrium with carbon (boydenite) and with cementite (austenite) are essentially different in kind; makes calculation showing that densities of austenite and boydenite at 1650 degrees Fahr. are consistent with certain simple and well-defined differences in atomic arrangement; besides adding to knowledge of theory of graphitization, this paper is believed to be original demonstration that solute atom of any kind can occupy either of two types of location in lattice of given solvent.

LIMITING STATES. Limiting States of Ferrous Alloys (Sur les etats limites des alliages), L. Grenet. Academie des Sciences—Comptes Rendus, vol. 183, no. 15, Oct. 11, 1926, pp. 600-603, 1 fig. Mechanism of transformation of alloys from one crystalline state to another is discussed with special reference to alloys of iron with aluminum, silicon and cobalt; change may take place suddenly or through intermediate state in which properties of both phases are detectable; theory is suggested in which existence of limiting states is assumed.

IRON AND STEEL

BIBLIOGRAPHY. Review of Iron and Steel Literature, E. H. McClelland. Blast Furnace & Steel Plant, vol. 15, no. 1, Jan. 1927, pp. 5-9. Annual review covering publications bearing on geology, metallurgy, economics, forging and foundry practice, and other allied fields.

IRON CASTINGS

GASOLINE ENGINES. The Manufacture of Iron Castings for Petrol Engines, W. J. Molyneux. Foundry Trade Jl., vol. 35, nos. 543 and 544, Jan. 13 and 20, 1927, pp. 27-31 and 49-53, 33 figs. Explains methods commonly used in manufacture of such castings and shows novel devices of which author has made use during 10 years' experience. Coremaking; pouring cylinder castings.

MAGNESIUM

PROPERTIES. Magnesium and Its Alloys. Am. Mach., vol. 66, no. 2, Jan. 13, 1927, p. 69. Heat treating; machining alloys. Reference-book sheet.

MAGNESIUM ALLOYS

FOUNDING. Magnesium (Le Magnesium), R. DeFleury. Revue de Métallurgie, no. 11, Nov. 1926, pp. 649-657. Deals almost entirely with founding of magnesium and its alloys; in author's belief, chief difficulty to be overcome in exploitation of magnesium alloys for engineering lies in foundry, that is, in melting and preparation of alloys and in casting; chief difficulty in melting shop arises from great chemical activity of molten metal; contact with furnace gases must be rigorously avoided; problem of purification of melts and production of sound castings appears to have been most successfully solved in France by Michel (Societe du Magnesium Industriel), which is also successfully producing forgings of various kinds; engineering practice tends more towards development of forged parts, whereas outside France, attention has centered on castings. See translated abstract in Metallurgist (Supp. to Engr.), Jan. 28, 1927, pp. 14-15.

MALLEABLE IRON

MANUFACTURE. Manufacture of Malleable Iron, A. E. White. Am. Soc. for Steel Treating—Trans., vol. 11, no. 2, Feb. 1927, pp. 245-263, 20 figs. Considers composition, physical properties, and structural constitution of malleable iron and sets forth results of numerous experiments in series of tables, showing, by means of photomicrographs, changes in structure of cast iron when brought to various temperatures; curves show graphical expressions of time-temperature relations for equilibrium of cast iron of varied carbon and silicon content; author attaches much importance to cooling-down process; sets forth variation in time required to produce equilibrium in iron-carbon alloys of composition usually used in making malleable cast iron.

MANGANESE STEEL

WELDING. To Weld Manganese Steel. Diesel Oil Engine Jl., vol. 2, no. 6, Jan. 1927, 23. Preheating and heat treatment after welding are necessary for work on this metal.

METALLOGRAPHY

MICROSCOPIC EXAMINATION OF METALS. Application of Microtome Methods to the Preparation of Soft Metals for Microscopic Examination, F. F. Lucas. Am. Inst. Min. & Met. Engr.—Trans., no. 1654-E, Feb. 1927, 15 pp., 16 figs. Describes sectioning method for preparing soft metals for microscopic examination and illustrates its application; microtome methods can be applied successfully to preparation of soft metals.

METALS

ACID-RESISTING. Acid-Resisting Engineering Metals (Das Problem der säurefesten metallischen Werkstoffe), W. Guertler. Zeit. für Metallkunde, vol. 18, no. 12, Dec. 1926, pp. 365-376, 21 figs. Chemical susceptibility and affinity of metals; direct, thermochemical and electrochemical methods of determining relationship of metals; behavior of metals in electrolytes; behavior of heterogeneous alloys; behavior of metallides.

COLD WORKING OF. Materials Employed in Working of Metals (Quelques nouveautés dans le travail à froid des métaux), J. Cournot. Technique Moderne, vol. 18, no. 23, Dec. 1, 1926, pp. 753-757, 9 figs. Advantages and disadvantages of lead addition before drawing; pickling; tempering; duplex and triplex plate; material employed in cold working; control of products.

FATIGUE TESTING. Design of Specimens for Short Time "Fatigue" Tests, L. B. Tuckerman and C. S. Atchinson. Diesel Oil Engine Jl., vol. 2, no. 6, Jan. 1927, pp. 25-28, 10 figs. Discusses controlling factors in design of short-time fatigue-test specimens which differ from those of endurance-run type of fatigue tests; load-deflection and load-temperature rise methods of tests seem to promise to be of value for limited classes of material;

Sondericker type of rotating-beam fatigue machine with plain cylindrical specimen or specimen with slightly reduced cylindrical section between load bearings, seems best suited for these tests.

FLOW IN. Testing Flow in Metals At Various Temperatures, L. W. Spring, H. W. Maack and J. Kanter. Power, vol. 65, no. 6, Feb. 8, 1927, pp. 205-208, 4 figs. Deals with new machines designed for accurate testing of flow or creep in metals in which test specimens are subjected to maintained high temperatures and pressures prevalent in modern practice; materials having tensile strengths up to 250,000 pounds per square inch may be tested.

HARDENING. General Theory of Metallic Hardening, R. S. Dean and J. L. Gregg. Am. Inst. Min. & Met. Engrs.—Trans., no. 1644-E, Feb. 1927, 18 pp., 7 figs. Theory of hardening by binding of electrons at lattice discontinuities as proposed by Dean has been developed in considerable detail; authors' theory is that this binding of electrons results in formation of definite diatomic non-polar molecules.

RESEARCH. Physics and Technology in the Analysis of Materials (Physik und Technologie in der Stoffkunde), G. Masing. Maschinenbau, vol. 5, nos. 23 and 24, Dec. 2 and 16, 1926, pp. 1071-1075 and 1130-1133, 17 figs. Points out differences between scientific and technical problems, and describes how cold working of metals was investigated technically and scientifically; only since very recent date has progress been made by simultaneous technical and physical investigations.

SPECIFIC HEAT. On the Latent Heat of Fusion of Several Metals and Their Specific Heats and High Temperatures, S. Umino. Tohoku Imperial Univ.—Science Reports, vol. 15, no. 5, Nov. 1926, pp. 597-617, 11 figs. Gives melting point for iron, chromium, etc. (In English.)

SPECIFIC HEAT. Specific Heat of Metals at Low and at Very High Temperatures (Chaleur spécifique des métaux aux basses et très hautes températures), G. Moressée. Revue Universelle des Mines, vol. 12, no. 6, Dec. 15, 1926, pp. 217-239, 1 fig. Ultra-violet waves characteristic of metals; rotational energy of atoms; total atomic mechanical energy; investigation to determine specific heat in function of temperature; application to lead and silver.

MONEL METAL

SHIP-MACHINERY PARTS, FOR. Monel Metal. Shipbldr., vol. 34, no. 197, Jan. 1927, pp. 64-65, 2 figs. Vital moving and controlling parts in boilers, steam line and turbines of steamship King George V are made of monel metal; this material is used for valves, valve seats and spindles; reasons for extensive adoption of monel metal lie in its combined qualities of resistance to corrosion and strength at high temperatures.

NICKEL

PROPERTIES. Physical Properties of Engineering Materials. Power Engr., vol. 22, no. 250, Jan. 1927, pp. 27-29, 5 figs. Electrical and thermal conductivity; nickel alloys.

PROPERTIES. Position of Nickel in Modern Metallurgy, W. R. Barclay. Metal Industry (Lond.), vol. 30, no. 1, Jan. 7, 1927, pp. 25-29, 3 figs. Summarizes place of nickel in modern metallurgy and nature and properties of its more important alloys; it is one of metals which, in its tensile properties, can rival in strength alloys of steel, and its non-corroding qualities make it of special value in many applications of modern high-power and electrical engineering.

NICKEL ALLOYS

CHROMIUM-NICKEL. Vitalizing Oil Engine Valves With Nickel. Oil Engine Power, vol. 5, no. 2, Feb. 1927, pp. 97-98, 6 figs. Chromium-nickel alloys as safeguard against combined mechanical and thermal hard usage.

NICKEL STEEL

DENSITY. The Relation Between Lattice Constants and Densities in Nickel-Steels, A. Osawa. Tohoku Imperial Univ.—Science Reports, vol. 15, no. 5, Nov. 1926, pp. 619-630, 5 figs. Deals with influence of carbon upon space lattice of iron-nickel alloys; lattice constants, density and hardness of iron-nickel alloys are affected by addition of carbon. (In English.)

NONFERROUS METALS

PRODUCTION, 1926. Nonferrous Metals in 1926. Metal Industry (Lond.), vol. 30, no. 4, Jan. 28, 1927, p. 113. World survey.

RESEARCH. Research on Non-Ferrous Metals. Mining & Met., vol. 8, no. 241, Jan. 1927, pp. 6-7. Institute of Metals Division prepares list of research problems; organizations planning research work in these problems requested to notify committee; more problems invited.

UNITED STATES, 1926. Non-Ferrous Metals in the U. S. A. for 1926, W. M. Corse. Metal Industry (Lond.), vol. 30, no. 1, Jan. 7, 1927, pp. 39-40. Copper is leading nonferrous metal; corrosion in nonferrous metals; in brass there is distinct trend away from high zinc alloys towards higher copper alloys; development of nickel; progress in magnesium; lead and zinc; spelter situation; aluminum.

OPEN-HEARTH FURNACES

COKE-OVEN GAS FOR. Coke Oven Gas for Open-Hearth Furnaces, C. Longenecker. Blast Furnace & Steel Plant, vol. 15, no. 1, Jan. 1927, pp. 32-33 and 36, 3 figs. Discusses developments in application of coke-oven gas and present practice in use of both gas and tar, and economies effected.

COOLING. Cooling of Open-Hearth Furnaces (Die Kühlung von Siemens-Martin-Oefen), G. Bulle. Stahl u. Eisen, vol. 47, no. 2, Jan. 13, 1927, pp. 41-52, 37 figs. Purpose of cooling; different arrangements and devices; heat requirement, durability and operating costs; advantages and disadvantages of cooling.

DEVELOPMENTS. Developments in the Open-Hearth Process, B. M. Larsen. Blast Furnace & Steel Plant, vol. 15, no. 1, Jan. 1927, pp. 10-15, 1 fig. Review of furnace construction and operation; metallurgical practices (with chemical equations). Bibliography.

OXYACETYLENE WELDING

IMPURITIES, INFLUENCE OF. Influence of Oxygen and Acetylene Impurities on the Quality and Economy of Welded Seams (Einfluss der Verunreinigungen von Sauerstoff und

Acetylen auf die Güte und Wirtschaftlichkeit der Schweissnaht), Streb. Autogene Metallbearbeitung, vol. 19, no. 23, Dec. 1, 1926, pp. 305-314 and (discussion) 314-320, 10 figs. Review of former experiments, and account of tests carried out by author; results show that when welding with standard equipment, such as are commonly used, impurity in oxygen up to 5 per cent plays no role; nitrogen content up to 5 per cent in oxygen and content of up to 0.007 H_2S and 0.02 PH_3 in acetylene has no influence on quality on welded seam.

TESTING WELDS. Testing Gas Welds, H. L. Whittemore. Welding Engr., vol. 12, no. 1, Jan. 1927, pp. 38-40. Review of present testing methods with suggestions for testing devices and further research in welding problems.

PIPE, CAST-IRON

CENTRIFUGALLY CAST. Casts Pipe Centrifugally, E. C. Kreutzberg. Foundry, vol. 55, nos. 2 and 3, Jan. 15 and Feb. 1, 1927, pp. 49-51 and 102-104, 10 figs. Describes new De Lavaud plant at Burlington, N. J., located on Delaware River; it comprises 8 centrifugal machines, of which 5 are operated regularly, having total output of 1200 lengths of 4 to 12-inch pipe a day; 4 cupolas comprise present melting equipment.

FRENCH. Tests of French Cast Iron Pipe. Iron Age, vol. 119, no. 2, Jan. 13, 1927, pp. 140-141. In comparison with American pipe it shows equal strength, greater hardness, but lower impact and deflection values.

TESTS. Test Results on Cast Iron Pipe. Iron Age, vol. 119, no. 3, Jan. 20, 1927, pp. 214-216, 7 figs. Comparison between French and American pipe, made by United States Bur. of Standards; new test methods advocated.

RAILS

WELDED BONDS. Electrification Proves Merits of Welded Rail Bonds, W. P. Bovard. Ry. Signaling, vol. 20, no. 2, Feb. 1927, pp. 47-48, 5 figs. Both oxyacetylene and electric arc welding are extensively used in electric railway field for bonding track; gives extensive application of gas-weld bonds.

REFRACTORIES

ZIRCALLITE. Zircallite, A New Preventive Against the Destruction of Furnace Linings (Ein neues Schutzmittel gegen die Zerstörung von Ofenauskleidungen), M. Berger. Feuerungstechnik, vol. 14, no. 21, Aug. 1, 1926, pp. 254-255. Patent mixture containing zirconia gives excellent protection to grog and silica materials, particularly in powdered-coal and oil furnaces, Martin furnaces, etc.; when used as mortar it fuses with brickwork to form monolithic structure.

ROLLING MILLS

A. C. MOTORS FOR. General Specifications of A. C. Motors for Main Roll Drive. Iron & Steel Engr., vol. 4, no. 1, Jan. 1927, pp. 29-34. Results of two years' discussion on subject of Standardization of Rating of Large Rolling Mill Motors; they represent consensus of opinion of not only large majority of users, but also of designers of such motors.

ELECTRIC DRIVE. Hot Rolling. Electric Control of Rolling Mills (Le travail à chaud Les méthodes actuelles de commande électrique des trains de laminoirs), J. Levy. Technique Moderne, vol. 18, no. 23, Dec. 1, 1926, pp. 751-752, 4 figs. Discusses drives by d. c. and by a. c. motors.

ELECTRIC DRIVE. Main Roll Drives in the United States and Canada. Iron & Steel Engr., vol. 4, no. 1, Jan. 1927, pp. 55-87. Information in uniform manner showing horsepower, r. p. m., voltage, cycles, type and size of mill, method of drive, date of purchase, name of plant and location; also classified list which gives types of installations in blooming, plate, rail and structural mills, bar and billet, sheet bar and skelp mills, sheet and tinplate plants, rod, piercing, tube, strip and hoop mills, merchant, wire, and wheel mills, aluminum, brass, copper and nonferrous mills; also multispeed drives, a. c. speed sets, d. c. adjustable speed drives and reversing blooming-mill drives; data has been prepared with view of providing executives and engineers in iron and steel industry an authority, and reference manual for their guidance in future installations and extensions.

ELECTRICAL EQUIPMENT. Electric Equipment for Steel Plants. A. F. Kenyon. Blast Furnace & Steel Plant, vol. 15, no. 1, Jan. 1927, pp. 37-39 and 46, 10 figs. Progress in design and construction of motors for driving mills of various types; equipment for mills at various steel plants.

ELECTRIFICATION. Steel-Mill Electrification in 1926. Iron Age, vol. 119, no. 2, Jan. 13, 1927, pp. 137-138. Large units prominent; individual drive on separate stands of continuous mills; improvements in adjustable-speed drives.

EQUIPMENT. Improvements in Rolling Mill Equipment, F. C. Roberts, Jr. Blast Furnace & Steel Plant, vol. 15, no. 1, Jan. 1927, pp. 29-31, 6 figs. Factors controlling rolling-mill construction; changes to various types of mills indicate material advances; pilger mill attracting much attention.

INDIVIDUAL DRIVE. Individual Drive Gains Favor, J. D. Wright. Iron Trade Rev., vol. 80, no. 4, Jan. 27, 1927, pp. 267-268, 1 fig. Numerous high-powered mill installations built recently have each stand of rolls coupled to single motor; d. c. machines are finding wider application; examples of new mill arrangements.

MERCHANT MILL. New Merchant Mill Placed in Operation, C. Longenecker. Blast Furnace & Steel Plant, vol. 15, no. 1, Jan. 1927, pp. 16-19, 3 figs. Layout and operation of new 10-inch Morgan merchant mill; electrical and mechanical features.

TUBE. American Rolling Mills for Manufacture of Tubes (Amerikanische Rohrwalzwerksanlagen), H. Koppenberg. Stahl u. Eisen, vol. 47, no. 1, Jan. 6, 1927, pp. 17-25, 22 figs. Outstanding features of American tube-making process; seamless tubes; butt- and lapped-welded tubes; methods and equipment of National Tube Co., Pittsburgh Steel Products Co., Timken Roller Bearing Co., Youngstown Sheet and Tube Co.

TUBE. Oil Industry and Production of Seamless Tubes in the United States (Oelindustrie und Erzeugung nahtloser Röhre in den Vereinigten Staaten), F. Rosdeck. Stahl u. Eisen, vol. 47, no. 1, Jan. 6, 1927, pp. 9-17, 20 figs. Oil production in United States; different types of tubes employed in oil industry; most important tube-making

processes; comparison of American and European methods; probable trend of development in American tube rolling mills.

SLAG

CUPOLA. The Iron Content of Cupola Slags in Relation to the Melting Temperature and the Limestone Content, E. Diepschlag. Foundry Trade Jl., vol. 35, no. 543, Jan. 13, 1927, p. 34, 1 fig. Results of experiments show that at high melting temperatures amount of iron loss not only depends upon chemical influences but also upon physical ones. Translated from Giesserei, no. 45, 1926.

CUPOLA. Metallography of Iron Spheres Contained in Cupola Slag (Beitrag zur Metallographie der in Kupolofenschlacke eingeschlossenen Eisenkugeln), F. Roll. Giesserei, vol. 14, no. 2, Jan. 8, 1927, pp. 21-23, 8 figs. Chemical and metallographic analyses show that small iron granules have ferritic border zone, whereas in the case of larger iron spheres, ferritic-pearlitic structure was observed on edge as well as in center of slide.

STEEL

AUSTENITIC STRUCTURE. The Decomposition of the Austenitic Structure in Steels, R. L. Dowdell and O. E. Harder. Am. Soc. for Steel Treating—Trans., vol. 11, no. 2, Feb. 1927, pp. 217-232, and 338, 31 figs. Decomposition of austenite during quenching; study is made under two headings, (1) ordinary quenching conditions and (2) special consideration of high stresses produced during quenching.

BOLT. Investigation of Bolt Steels, V. T. Malcolm and J. Juppenlatz. Am. Soc. for Steel Treating—Trans., vol. 11, no. 2, Feb. 1927, pp. 177-216 and 299, 40 figs. Results of investigations made upon bolts and bolt materials obtained after several years of study, covering tests upon failures under actual working conditions, remedies and recommendations; not only heat treatment, physical tests and chemical analysis of raw material are important, but method of manufacture, rigid inspection and safeguards are specially necessary for highly or heavily stressed parts; recommends heat-treated alloy steel bolt to supplement carbon steel bolt and gives results of tests upon both of these materials; modern testing methods, with special reference to methods of high-temperature short and long-time testing; test data and charts pertaining to bolt material; in author's opinion, all advantages claimed for case-hardened nuts may be had without bad effects by use of medium-carbon heat-treated steel nut. Bibliography.

BRITTLENESS. On the Impact Test of Steels at Low Temperatures, R. Yamada. Tohoku Imperial Univ.—Science Reports, vol. 15, no. 5, Nov. 1926, pp. 631-659, 22 figs. For investigation of brittleness of steels, single bending and tension impact test and repeated impact test were made; materials tested were plain carbon and alloy steels with pearlitic and sorbitic structures; brittleness increases generally with fall of temperature and steels with sorbitic structure are much tougher than those with pearlitic structure at all temperatures; tested in annealed condition, steels alloyed with nickel and chromium are tougher than plain carbon steels, and increase in brittleness with fall of temperature is comparatively slight. (In English.)

CARBURIZED VS. CAST. Wear Resistance of Carburized Steel Versus Cast High Manganese Steel, W. J. Merten. Am. Soc. for Steel Treating—Trans., vol. 11, No. 2, Feb. 1927, pp. 233-244, 7 figs. Experiments made to determine comparative wear resistance of 14 per cent manganese cast steel and case-hardened steel when subjected to relatively high pressure with movements free from shock or pounding; plastic flow under heavy pressure, during gliding motion is apparently cause of considerable abrasion on manganese steel while it has decidedly less influence upon case-hardened steels.

CASE-HARDENED. Gas Cementation and its Influence on Core Properties in Case-hardened Steels (Die Gastiefenzementation und ihr Einfluss auf die Eigenschaften des Kernes im Einsatz gehärteter Stähle), W. Rohland. Stahl u. Eisen, vol. 47, no. 2, Jan. 13, 1927, pp. 52-57, 4 figs. Results of cementation tests on two carbon steels and chromium-nickel steel in coal-gas atmosphere, influence of different temperature and duration of cementation on its depth; coarsening of grain core strength and structure; most suitable heat treatment.

CORROSION. Effect of Velocity on Corrosion of Steel Under Water, R. P. Russell, E. L. Chappell and A. White. Indus. & Eng. Chem., vol. 19, no. 1, Jan. 1927, pp. 65-68, 5 figs. Presents data showing that when cleaned or polished steel is corroded under water for short periods, corrosion may be high at low velocities and becomes less with further increases in velocity; when steel is rusted previously, however, corrosion at high velocities is greater than corrosion observed at very low velocities; in other words, presence of rust film greatly alters corrosion rate.

FATIGUE. The Variation in the Fatigue Strength of Metals When Tested in the Presence of Different Liquids, G. D. Lehmann. Engineering, vol. 122, no. 3181, Dec. 31, 1926, pp. 807-809, 7 figs. Results of research carried out by Engineering Laboratories, Oxford, and published by permission of Engineering Research Board; it appears that hot aqueous solutions of sodium chloride, ammonium salts (excepting nitrate), sodium nitrate and ammonium hydroxide at 17 degrees Cent. show no cracking action on stressed steel, while hot sodium nitrate solution causes fractures, which appear to be similar to those caused by ammonia, ammonium salts, mercuric and mercurous salts in brass; lubricating oil at 17 degrees Cent. produces no change in fatigue strength.

HARDNESS. The Hardness of Different Structures in Steel. Chem. Age, vol. 16, no. 393, Jan. 8, 1927, pp. 1-3. Results of investigation; effect of cooling; manganese steel at high temperature; austenite, martensite and troostite. Abstracted from Scientific Papers of Inst. Phys. and Chem. Research of Tokio, vol. 5, no. 67, p. 25.

MAGNETIC PERMEABILITY. Magnetic Permeability of Cold-Drawn Steels (De la pérmeabilité magnétique des aciers étirés à froid), G. Delbart. Académie des Sciences—Comptes Rendus, vol. 183, no. 16, Oct. 18, 1926, p. 662. Magnetic permeability of steel studied after annealing at 15, 700, 850 and 980 deg.; at 700 degrees Cent. globular pearlite structure was observed, giving place almost

entirely to sorbitic pearlite structure at 850 and 980 degrees Cent.; this change is accompanied by increase in magnetic permeability.

PHOSPHORUS AND ARSENIC IN. Phosphorus and Arsenic in Steel and the Substitution Theory, A. E. Cameron. Can. Min. & Met. Bul., no. 177, Jan. 1927, pp. 88-98, 4 figs. Interesting points brought out in comparing relative effects of arsenic and of phosphorus in steel upon physical properties. Bibliography.

REINFORCED CONCRETE, VS. Why I Prefer Steel to Reinforced Concrete, G. F. Swain. Boston Soc. Civ. Engrs.—Jl., vol. 14, no. 1, Jan. 1927, pp. 1-30 and (discussion) 31-66. Author compares reinforced concrete with steel and iron, and gives reasons for his conviction that reinforced concrete has been and is being very much over-advertised, over-praised and over-boomed, with result that it has been and is being used in many cases where steel is decidedly preferable. Paper presented to Am. Inst. Steel Constr.

SILICON IN. An Etching Reagent for Silicon in Steel (Ein spezifisches Aetzmittel für Silizium im Eisen), P. Oberhoffer. Stahl u. Eisen, vol. 46, no. 35, Sept. 2, 1926, pp. 1191-1192. Describes action of iodine solution as etching reagent which responds to presence of silicon, while indifferent, in conditions employed, to carbon, manganese, etc.; etching solution employed consists of 1 to 10 solution in alcohol of deci-normal iodine solution; steels free from silicon are unaffected by this reagent, while steel containing appreciable proportions of silicon are more or less deeply pitted. See brief translated abstract in Metallurgist (Supp. to Engr.), Dec. 31, 1926.

SOLIDIFICATION. Solidification of Steel in the Ingot Mold, A. L. Feild. Am. Soc. for Steel Treating—Trans., vol. 11, no. 2, Feb. 1927, pp. 264-275 and (discussion) 276 and 338, 1 fig. Linear rate of solidification of steel and location and shape of shrinkage cavity, with certain simplifying assumptions are treated mathematically; from this standpoint, methods employed are capable of further development to apply to actual mold practice, provided some of physical properties of steel and mold material (cast iron) at high temperatures are determined experimentally; in case of steel poured at its melting temperature, maximum rate of solidification is shown to be inversely proportional to square root of elapsed time, measured from moment of contact between liquid steel and mold wall, and distance through which solidification has progressed directly proportional to square root of elapsed time; effect of degree of superheat above melting temperature and of mold-wall thickness upon solidification rate.

STAINLESS. Stainless or Non-Corrosive Steel, A. C. Jebens. Eng. Progress, vol. 8, no. 1, Jan. 1927, pp. 23-24, 5 figs. Firm of Krupp manufactures two kinds of stainless steel; first group shows properties resembling those of chromium-nickel steel; percentage of chromium is about 13 to 15 per cent with small addition of nickel; these steels can be magnetized and their designation is VM; second group comprises so-called VA steels that cannot be magnetized; they are characterized by their exceedingly high resistance to corrosive processes of every description as well as their great welding strength.

STAINLESS. Stainless Steel, A. E. White and C. L. Clark. Univ. of Michigan, Dept. of Eng. Research, no. 4, Nov. 1926, 82 pp., 10 figs. Digest of Literature; abstracts of important articles; bibliography; graphical studies.

STEEL, HEAT TREATMENT OF

AUSTENITE AND MARTENSITE TRANSFORMATION. Transformations of Austenite and Martensite in Hardened Steels (Die Umwandlungen des Austenits und Martensits in Gehärteten Stählen), G. Tammann and E. Scheil. Zeit. für anorganische und allgemeine Chemie, vol. 157, no. 1-3, 1926, pp. 1-21, 18 figs. When hardened steel is cooled continuously from 20 to —150 degrees Cent., conversion of austenite into martensite commences at about —20 degrees Cent., and continues to —150 degrees Cent., change occurs, however, to greater extent near surface than it does within mass, possibly because of retarding effect of high pressures prevailing in interior; temperature at which rate of transformation into pearlite commences to be appreciable is about 100 degrees Cent. for martensite, and 250 degrees Cent. for austenite.

CARBONIZING. Comparative Carbonizing Costs. Gas Age-Rec., vol. 59, no. 1, Jan. 1, 1927, pp. 21-22. Gas-fired rotary carbonizing machines versus oil-fired oven-type semi-muffle furnaces.

ELECTRIC. Notes on the Use of Electric Power for Forging, Normalizing and Hardening Drill Steel Bits, E. D. Brunner, S. African Inst. Elec. Engrs.—Trans., vol. 17, Oct. 1926, pp. 247-256, 10 figs. Describes how electricity has been used for different processes, such as welding broken steel and shanking, heating for forging, heating for hardening, and normalizing.

STEEL, HIGH-SPEED

VANADIUM DETERMINATION IN. Determination of Vanadium in High-Speed Steels (Die Bestimmung des Vanadins in Schnellstählen sowie dessen Abbrand bei Erzeugung dieser Stähle), A. Fölsner. Stahl u. Eisen, vol. 47, no. 1, Jan. 6, 1927, pp. 28-30. Discusses value of vanadium as alloying constituent, and methods of analysis; losses of vanadium in production of steel; they are probably due to association of vanadium with free oxygen, and not with oxides of bath.

STRUCTURAL STEEL

HIGH-SILICON. High Silicon Structural Steel, H. W. Gillett. U. S. Bur. of Standards—Technologic Papers, no. 331, Nov. 1, 1926, pp. 121-143, 10 figs. German steel, known as "Freund" steel, has aroused interest of structural engineers; test results on specimens submitted to Bureau of Standards, showing steel to combine desirable properties of high yield point and high ductility; it is unusually high in silicon, containing about 1 per cent, and low in carbon, containing less than 0.15 per cent; recent American practice in manufacture of high yield-point structural steel has tended toward use of manganese as alloying element; from sole basis of cost of alloying element silicon should be nearly as cheap as, and sometimes cheaper than manganese and considerably cheaper than nickel; hence, attention of American steel makers is called

to possibilities of its use; summary of published data on alloying effect of silicon and manganese; presents evidence which leads to conclusion, contrary to some German claims, that no special type of furnace is required for manufacture of silicon steel.

HIGH-SILICON. The Properties of Silicon-Rich Structural Steel (Die Eigenschaften des hochsilizierten Baustahls), E. H. Schulz and H. Bucholts. Giesserei Zeitung, vol. 23, no. 24, Dec. 15, 1926, pp. 687-689, 1 fig. Discussion of paper published in same journal, Nov. 15, 1926, pp. 615-622.

MERITS AND ADVANTAGES. The Merits and Advantages of Steel, B. Stoughton. Can. Machy., vol. 37, no. 1, Jan. 6, 1927, pp. 23-27. Properties and manufacture of steel; compared with other kinds of structural materials, it is homogeneous and the only simple and ductile material; pliability of steel; steel vs. concrete. (Abstract.) Address before Am. Inst. of Steel Construction.

RESEARCH. Research Investigations in Connection with the Structural Steel Industry, M. S. Ketchum. Eng. & Contracting, vol. 66, no. 1, Jan. 1927, pp. 11-15. What economic design requires; definitions of steel: common alloys; impact and secondary stresses; riveted joints; welding; torsional stresses in steel members; steel columns; fire-resisting qualities. Paper presented at convention of Am. Inst. Steel Construction.

THERMIT WELDING

RAIL JOINTS. Thermit Welding of Rail Joints (Schienenstosserneuerungen durch Thermitschweissung). Verkehrstechnik, vol. 43, no. 50, Dec. 10, 1926, pp. 851-852, 5 figs. Description and costs of renewal of joints in street-railway rails.

TIN

METALLURGY AND APPLICATIONS. Tin: Its Metallurgy and Applications, A. H. Mundey. Metal Industry (Lond.), vol. 30, no. 1, Jan. 7, 1927, pp. 11-15. Notes on its principal alloys; production of bronze; tin for tin plates; white metals; printers' alloys; function of tin in refining structure; fusible alloys.

TUNGSTEN

DEVELOPMENTS. Tungsten and Chromium, C. H. Smithells. Metal Industry (Lond.), vol. 30, no. 1, Jan. 7, 1927, pp. 31-32, 1 fig. Deals with latest developments; chromium, apart from its uses as an alloy in heat-resisting materials, is coming more and more into favor for electroplating.

WELDING

CAST ALUMINUM. How to Weld Cast Aluminum. Diesel Oil Engine Jl., vol. 2, no. 6, Jan. 1927, pp. 39-41, 8 figs. Methods which have been successfully used in repair shops and foundries.

FUSION. PERMANENT FRACTURE. Fusion Welding and Permanent Fracture (Schmelzschweissung und Dauerbruch), P. H. Schottky. Kruppsche Monatshefte, vol. 7, Dec. 1926, pp. 213-216, 11 figs. Reviews number of cases of broken structural and machine parts showing that fractures could be directly traced to welding applications, and explains why this method of repair is detrimental.

PROGRESS IN. Recent Progress in the Welding Field, R. E. Smythies. Can. Machy., vol. 37, no. 3, Jan. 20, 1927, pp. 22-26, 5 figs. Outlines progress made in both structural steel and machinery fields. Paper read before Eng. Inst. of Canada.

REPLACING CASTINGS BY. Replacing Castings With Welded Designs, W. L. Warner. Machy. (N. Y.), vol. 33, no. 6, Feb. 1927, pp. 421-424, 10 figs. Physical properties of cast iron and malleable castings; influence of welding on machine construction; advantages of welding; examples of welded designs.

STELLITING. Stelliting: A New Welding Process, A. V. Harris. Mech. Eng., vol. 49, no. 2, Feb. 1927, p. 123. "Stelliting" is neither welding nor brazing in ordinary sense of words; it calls for blowpipe flame which contains fairly large excess of acetylene to lower flame heat and to exclude as much atmospheric oxygen as possible; surface of base metal to which stellite is to be applied is brought up to such a heat that it just begins to sweat and assume oily appearance.

WIRE

COPPER, CONDUCTIVITY. Notes on the Relation of Annealing Temperature to Conductivity of Copper Wire, J. C. Bradley. Am. Inst. Min. & Met. Engrs.—Trans., Feb. 1927, 2 pp., 1 fig. Conductivity hard was 98.26 per cent; after a 10-minute heating at 200 degrees Cent. it was 98.69; by annealing 10 min. at 300 degrees Cent. large increase to 100.93 occurred; maximum conductivity, 101.15 was attained after 500 degrees Cent. anneal; thereafter it decreased to 100.53 after 950 degrees Cent. anneal; if copper is gassed decrease is much more than this.

WIRE DRAWING

DIAMOND DIES FOR. Diamond Dies for Wire Drawing. Metal Industry, vol. 30, no. 2, Jan. 14, 1927, pp. 65-67, 1 fig. Particulars of plant of British Diamond Wire Die Co. in Dorset; type of diamond needed for dies; drilling and mounting; care required in use of diamond dies.

X-RAYS

METAL EXAMINATION. Immersion of Metals in Homogeneous Media Opaque to X-Rays. Improvement in Radiographic Methods (Immersion des metaux dans des milieux homogenes opaques aux rayons X. Amelioration des methodes radiographiques), H. Pilon and A. Laborde. Academie des Sciences,—Comptes Rendus—vol. 183, no. 16, Oct. 18, 1926, pp. 658-659. It is suggested that to assist X-ray examination of metals of complicated form, in which absorption varies considerably from one part of the object to another, object to be tested should be immersed completely in homogeneous salt solution which has almost same absorption coefficient as metal; if solution penetrates all parts of object, whole of it is rendered visible; suitable concentrations of salt solutions are calculated for various metals.

METALLURGY, APPLICATION TO. Application of X-Rays in Metallurgy (Les applications des rayons X en métallurgie), Jean-Jacques Trillat. Revue de Metallurgie, no. 11, Nov. 1926, pp. 671-684, 25 figs. Properties of X-rays; absorption of X-rays by meter; diffraction; applications based on absorption and on diffraction.

News of the Society

MINUTES OF MEETING OF THE BOARD OF DIRECTORS

MAYFLOWER HOTEL, WASHINGTON, D. C., JANUARY 19, 1927

Present

J. F. HARPER
F. G. HUGHES
DR. ZAY JEFFRIES
W. H. EISENMAN
R. M. BIRD
R. G. GUTHRIE
HYMAN BORNSTEIN
J. H. NEAD
L. D. HAWKRIDGE

Upon motion by Mr. Bird, seconded by Mr. Bornstein and unanimously carried, the following resolution of organization was adopted:

"Resolved: In order to comply with the laws of Ohio, in which the directors of the Society elect their own officers, it is hereby resolved that the following officers be elected for the American Society for Steel Treating for 1927:

J. F. Harper, president for one year;
F. G. Hughes, vice-president for one year;
W. H. Eisenman, secretary for two years;
Zay Jeffries, treasurer for one year.

The minutes of the previous meeting of the Board of Directors held in Chicago on September 22, 1926, were read and approved.

Upon motion by Mr. Bornstein, seconded by Mr. Bird and unanimously carried, the appointment of standing committees as submitted by President Harper was approved as follows:

FINANCE COMMITTEE

DR. ZAY JEFFRIES, Chairman

Members

J. V. Emmons, Cleveland
A. G. Henry, Chicago
J. M. Watson, Detroit
J. B. Dillard, Cleveland
A. O. Fulton, Boston

CONSTITUTION AND BY-LAWS COMMITTEE

S. M. HAVENS, Chicago, Chairman

Members

F. H. Franklin, Providence
O. T. Muehlemeyer, Rockford
F. G. Hughes, Hartford
W. P. Woodside, Detroit
H. J. Stagg, Syracuse

PUBLICATION COMMITTEE

Prof. H. M. Boylston, Chairman — Ray T. Bayless, Vice-chairman and Secretary

Members

G. C. Lilly, Lehigh Valley
C. M. Johnson, Pittsburgh
A. H. d'Arcambal, Hartford
S. C. Spalding, Syracuse
J. L. McCloud, Detroit
Jerome Strauss, Washington
E. E. Thum, New York
B. F. Shepherd, Lehigh Valley
A. W. F. Green, Philadelphia
E. C. Bain, New York

MEETINGS AND PAPERS COMMITTEE

W. B. Coleman, Chairman — Ray T. Bayless, Secretary

Members

E. E. Thum, New York
E. C. Bain, New York

RECOMMENDED PRACTICE COMMITTEE

W. J. Merten, General Chairman — J. E. Donnellan, Secretary

Members

J. A. Mathews, New York
H. M. Northrup, Detroit
J. H. Gibboney, Roanoke
P. C. Osterman, New York
G. H. Wright, Schenectady
R. S. Archer, Cleveland
F. C. Langenberg, Boston

JOINT COMMITTEE ON HEAT TREATMENT DEFINITIONS

A. S. S. T., A. S. T. M. and S. A. E. representatives—
J. F. Harper, Bradley Stoughton and W. J. Merten

It was decided that the secretary should correspond with the members of the A. S. S. T. representing the Society on Co-operative Committees, in order to determine the advisability of continuing this particular activity and that power should rest with President Harper to reappoint such co-operative members as it was found advisable to continue.

Treasurer Jeffries then submitted an audited treasurer's report for the year 1926. (See auditor's report on Page 494.)

It was moved by Dr. Jeffries, seconded by Mr. Hawkridge and unanimously carried that the report for the 1926 Convention be accepted and the Board expressed its appreciation to the Convention Committee.

The proposed budget for the year 1926-27 was then presented by Treasurer Jeffries. After discussion and a few changes, it was upon motion by Dr. Jeffries, seconded by Mr. Bornstein and unanimously carried, adopted as follows:

Proposed Budget for Year 1927

INCOME	
Gross Dues	$ 57,000.00
Transactions Advertising	50,000.00
Transactions Sales	1,000.00
Transactions Subscriptions	1,500.00
Reprints	1,000.00
Bindery Account	1,000.00
Book Account	2,000.00
Miscellaneous Items	500.00

Proposed Budget for Year 1927 *(Continued)*

Data Sheets	3,500.00
Discounts Received	500.00
Interest	5,000.00
Index	500.00
1927 Convention	90,000.00
	$213,500.00

EXPENSE

Local Chapters	22,500.00
Sectional Meetings	1,000.00
Increase of Membership	1,000.00
Transactions	44,000.00
Reprints	1,500.00
Bindery Account	1,000.00
Book Account	1,700.00
Library	200.00
Data Sheets	7,000.00
Discounts Allowed	500.00
Miscellaneous Items	1,000.00
Index	3,500.00
Metallurgical Education	500.00
General Expense	6,650.00
Secretary's Office	17,000.00
President's Office	1,000.00
Treasurer's Office	3,500.00
Director's Expenses	2,000.00
National Committees	5,000.00
Reserves	1,950.00
1928 Convention	1,000.00
1927 Convention	90,000.00
	$213,500.00

Treasurer Jeffries then presented the report of the meeting of the Finance Committee, held in Cleveland on Saturday, January 15, 1927.

Present: Dr. Zay Jeffries, chairman; A. O. Fulton, J. M. Watson, J. V. Emmons. (Ex-officio), President Harper, Secretary Eisenman. *Absent:* Arthur G. Henry.

The committee visited the Equity Savings and Loan Company office and verified the savings deposit book with the records in the office of the Equity Savings and Loan Company.

They then visited the safety deposit vault at the East End office of the Cleveland Trust Company, examined and checked record of the bonds contained therein as well as the savings account at that branch of the Cleveland Trust Company.

The items covering bonds and savings as appear on the balance sheet attached herewith, were found to be correct.

Upon motion properly made, seconded and carried, the 1927 budget as presented above was voted and recommended to the Board of Directors.

Upon motion properly made, seconded and carried, it was recommened to the Board of Directors that bad accounts to the amount of $375.20 should be written off.

It was moved, seconded and unanimously carried, that recommendation be made to the Board of Directors to depreciate office furniture from its present value ($1431.65) to a book value of $500.00.

The question of investments of additional funds of the Society was then given consideration. It was moved, seconded and unanimously carried that the committee should recommend to the Board of Directors the investment of $10,000.00, at present in the savings account of the Equity Savings and Loan

Company, and that this money should be invested in securities outside of Cleveland; also that such other funds as are available for investment during the coming year should be invested in other securities than those representing Cleveland property.

It was recommended that Mr. Fulton of Boston, Mr. Watson of Detroit and Dr. Jeffries of Cleveland should make investigations relative to desirable investments and make a report. The committee further recommended to the Board of Directors that the inventory, attached herewith, be accepted.

2,312	Bound Vols. of Transactions	
792	Bound Vols. "Metallurgy of Iron & Steel".....	
	Bindery Inventory as above	2,708.00
14½	Reams Transactions Cover Stock	
105	Reams White Transactions Paper Stock	
	Transactions Paper & Cover Stock	
	Inventory as above	1,154.40
100	Data Sheet Binders	130.00
4	Reams Data Sheet Paper Stock	56.00
90	ASST Pins	37.80
25	ASST Pencils	43.75
		$4,129.95

Upon motion by Mr. Hughes, seconded by Mr. Nead, the recommendations of the Finance Committee pertaining to bad accounts, inventory, depreciation of furniture and recommendation relative to investments were unanimously accepted.

Mr. Eisenman presented a report relative to the 1927 Convention, giving the status of the activities at the time of the meeting of the Board, with reference to the facilities of the hall, labor conditions in Detroit, statement relative to possible types of entertainment for the members.

Upon motion properly made and seconded, the secretary was authorized to extend an invitation to the Society of Automotive Engineers to hold their Annual Production Meeting in Detroit the week of the Convention of the A. S. S. T. and the National Steel and Machine Tool Exposition.

Upon motion properly made, seconded and carried, the Board authorized an invitation to be extended to the Institute of Metals Division of the A. I. M. M. E. to prepare a session or otherwise participate in the annual meeting of the A. S. S. T. at Detroit.

Upon motion by Mr. Bornstein, seconded by Dr. Jeffries, President Harper and Secretary Eisenman were appointed as members of a committee with the power to make arrangements with representatives of the American Welding Society, relative to a joint meeting of their Society (A. W. S.) during the week of September 19th, 1927.

Upon motion by Dr. Jeffries, seconded by Mr. Bornstein, Hotel Statler at Detroit was selected as the official headquarters for the Convention of the A. S. S. T. and the National Steel and Machine Tool Exposition.

Director Guthrie then reported to the Board the arrangements made by the American Gas Association to participate in the exposition at Detroit.

Upon motion by Dr. Jeffries, seconded by Mr. Hughes, Messrs. J. M. Watson (Detroit), member of National Finance Committee, and Robert Atkin-

son (Detroit), chairman of the Detroit chapter, were appointed to represent the Board with Secretary Eisenman in completing the arrangements for the Detroit Convention and Exposition.

Upon motion by Mr. Bornstein, seconded by Dr. Jeffries, the dates of May 19 and 20 were selected for the Spring Sectional Meeting to be held in Milwaukee.

Correspondence was read from Secretary Bain of the A. I. M. M. E. extending an invitation to the A. S. S. T. to be their guest at the annual convention in February at such sessions of their Iron and Steel Committee and of the Institute of Metals as would be of interest to the membership. Upon motion properly made, seconded and carried, the Board expressed its acceptance of the invitation and also its appreciation.

President Harper submitted a report on Metallurgical Education.

Upon motion by Mr. Hughes, seconded by Mr. Bornstein and unanimously carried, $500.00 was appropriated for the preparation of a syllabus along the lines outlined in President Harper's report.

Upon motion by Mr. Guthrie, seconded by Dr. Jeffries and unanimously carried, the Montreal Group was promoted to that of a chapter. This was done in recognition of the splendid work accomplished by the members while operating as a group.

Mr. Eisenman reported that the cities in which surveys were being made relative to the advisability of the establishment of additional groups of the Society were Canton-Massillon; Dayton; Birmingham; Houston; Toledo and Columbus.

A report was presented outlining the proposed activities on the part of the Institute of Metals Division of the A. I. M. M. E. in the preparation of nonferrous data sheets for publication in the A. S. S. T. handbook, under the direction of R. S. Archer, chairman. This proposed activity received the hearty approval of the Board.

Upon motion properly made, seconded and carried, it was voted that a general index of the first ten volumes of the A. S. S. T. TRANSACTIONS should be made available to members of the Society sending in requests for the same, at the rate of $1.00 per index. This rate was made in view of the fact that each volume of the index would cost in the neighborhood of $2.75.

It was moved by Mr. Hughes, seconded by Dr. Jeffries and unanimously carried that the Constitution and By-Laws Committee be authorized to prepare changes in the Constitution upon the following items:

1. That the classification known as "associate" members should be eliminated and that all present associate members of the Society should become regular members with the same rights and privileges and dues as now enjoyed by those in the "member" class.

2. To eliminate the National Membership Committee under National Committees.

3. To eliminate the Research Committee under National Committees.

4. To eliminate National Meetings and Papers Committee and to transfer the activities of this committee to the Publication Committee.

5. Make such other changes in the Constitution as may be necessary in order to conform with the given items.

It was moved by Mr. Eisenman, seconded by Mr. Bornstein and unanimously carried that Dr. Jeffries be selected as the E. D. Campbell Memorial Lecturer for 1927.

The Board then had a joint meeting with the Publication Committee at which time the activities of the TRANSACTIONS were discussed and suggestions received.

It was moved, seconded and unanimously carried that all papers for sectional and annual meetings secured by the Meetings and Papers Committee should first be submitted to the Publication Committee before acceptance for presentation at a sectional or annual meeting.

It was moved by Mr. Bird, seconded by Mr. Hughes and unanimously carried that no paper for a sectional or annual meeting should be preprinted unless the paper is in the hands of the committee at least 60 days previous to the date for presentation and further, that no paper was to be presented at any annual or sectional meeting unless it was in the hands of the committee at least 30 days prior to the date of presentation.

Upon motion by Dr. Jeffries, seconded by Mr. Eisenman, the sum of $2400.00 was voted for editorial assistance.

It was moved by Mr. Hughes, seconded by Dr. Jeffries and unanimously carried that in 1928 there should be but one sectional meeting.

Upon motion properly made, seconded and carried the meeting adjourned.

(Signed) W. H. EISENMAN, *Secretary.*

FINANCIAL STATEMENT OF THE AMERICAN SOCIETY FOR STEEL TREATING FOR THE YEAR 1926

The official report of Nau, Taylor & Swearingen, certified public accountants, covering the results of their audit of the books of the society is submitted herewith.

This statement again shows a very healthy condition of our finances, the Society working within its income and making substantial increases to its surplus.

The "Income and Expense Statement" shows a large increase over our 1925 turnover which indicates a substantial increase in the society activities.

Full details of the audited report are herewith given. The official copy of this report is on file at the society offices and is open for the inspection of any interested members.

NAU, TAYLOR AND SWEARINGEN, the certified public accountants who made the audit certify as follows:

"We have made an audit of the books and accounts of the AMERICAN SOCIETY FOR STEEL TREATING for the year ended December 31, 1926, and, in our opinion, the Balance Sheet—Exhibit A, together with the annexed Income and Expense Statement—Exhibit B, and Surplus Reconciliation correctly present its financial status at December 31, 1926, and a summary of its financial transactions for the year then ended, basing the income from dues upon date of cash receipt and other income upon date of accrual irrespective of date of receipt."

NAU, TAYLOR & SWEARINGEN,
Certified Public Accountants.

EXHIBIT A—Balance Sheet December 31, 1926

ASSETS			
CASH			
Cleveland Trust Company—Commercial Account	$ 6,222.70		
Cleveland Trust Company—Savings Account	204.69		
Equity Savings & Loan Company—Savings Account	18,415.29		
Union Trust Company—Savings Account	5,305.60		
Petty Cash	25.00	$ 30,173.28	
INVESTMENTS			
Euclid Village, Ohio, 6% Water Bonds	2,000.00		
U. S. Treasury Certificates (Maturity Value $2,500.00)	2,315.00		
U. S. Liberty Bonds	28,000.00		
Cleveland Trust Securities Company 5½% Trust Bonds	15,000.00		
Fidelity Mortgage Company 5½% Land Trust Certificates	10,000.00		
University Club 5¼% Land Trust Certificates	5,000.00	62,315.00	
ACCOUNTS RECEIVABLE			
Advertisers	4,185.65		
Convention Exhibitors	7,722.10		
Miscellaneous—Book Sales, Data Sheets and Binders, Service Deposits, etc	3,196.53		
	15,104.28		
Less—Reserve for Past Due and Doubtful Accounts	515.05	14,589.23	
Accrued Interest—Investments		1,009.18	
Inventory—Publishing Supplies and Pins, Buttons and Pencils		4,129.95	
Furniture and Fixtures—Book Value		500.00	
DEFERRED EXPENSES			
Washington Sectional Meeting	103.20		
Convention, 1927	1,631.43	1,734.63	
TOTAL ASSETS			$114,451.27
LIABILITIES, RESERVES AND SURPLUS			
Chapters' Share of Dues		1,912.94	
Reserve for Dues Paid in Advance		10,000.00	
Permanent Convention Reserve		20,000.00	
H. M. Howe Medal Fund		5,000.00	
Surplus		77,538.32	
TOTAL			$114,451.27

EXHIBIT B—Income and Expense Statement Year Ended December 31, 1926

INCOME		
Advertising—Transactions and Convention Program	$ 49,642.60	
Membership Dues—Gross	49,047.18	
Exhibitors' Space—Chicago Convention	79,075.00	
Special Service to Exhibitors—Chicago Convention	31,901.24	
Exhibitors' Sustaining Membership	8,350.00	
Admissions	5,645.25	
Exhibitors' Badges and Banquet	3,046.00	
Magazine Sales and Subscriptions—Transactions	2,427.86	
Bindery Sales	1,007.86	
Pins and Buttons Sales	58.00	
Pencils Sales	52.60	
Data Sheets Sales	1,951.97	
Data Sheet Binder Sales	989.50	
Book Sales	1,776.74	
Reprint Sales and Miscellaneous Income	1,257.11	
Discount on Purchases	635.61	
Interest Earned on Bank Balances and Investments	4,052.69	
Interest Earned on H. M. Howe Medal Fund	212.50	
E. D. Campbell Memorial Lecture	1,540.00	
Total Income		$242,669.71
EXPENSES		
Dues Returned to Chapters	20,185.83	
Support of Chapters	1,164.12	
Increase of Membership	594.92	
Reprints	1,320.85	
Bindery Expense	109.77	
Book Purchases	1,425.62	
Pencils	53.54	
Pins and Buttons	54.60	
Library Expense	180.42	

Printing		1,456.14	
Discount Allowed		489.99	
Bank Exchange		3.95	
H. M. Howe Medal Fund Expense		100.00	
E. D. Campbell Memorial Lecture Expense		2,036.81	
Telephone and Telegraph—General		383.13	
Rent—General		2,700.00	
Postage—General		1,533.02	
Office Supplies		445.66	
Stationery		852.87	
Convention Expense—1925		5.25	
Collection and Legal Expense		57.20	
Insurance		397.64	
Reduction in Value of Furniture and Fixtures		906.65	
Transactions			
Printing	$ 14,611.51		
Paper and Cover Stock	7,303.82		
Cuts	2,554.70		
Postage	1,185.67		
Editor's Salary	5,200.00		
Editorial Assistance	838.50		
Editor's Traveling Expense	419.66		
Clerical Salaries	1,625.00		
Advertising Commissions	402.00		
Wrapping	300.73		
Executive Salary	2,750.00		
Miscellaneous Expense	125.12	37,316.71	
Data Sheets			
Paper Stock	314.13		
Editor's Salary	2,000.00		
Clerical Salaries	473.90		
Postage	539.12		
Binders	741.45	4,068.60	
Secretary's Office			
Executive Salary	4,400.00		
Assistant Secretary's Salary	1,750.00		
Clerical Salaries	3,111.00		
Traveling Expense	2,804.51		
Miscelleaneous Expense	590.99	12,656.50	
President's Office			
Traveling Expense	1,842.45		
Miscellaneous Expense	12.05	1,854.50	
Treasurer's Office			
Bookkeeper's Salary	2,700.00		
Auditing Services	373.50		
Miscellaneous Expense	48.34	3,121.84	
Directors' Expense			
Traveling Expense	1,912.94		
Miscellaneous Expense	163.33	2,076.27	
National Committees			
Salary	2,000.00		
Recommended Practice	1,146.80		
Finance	95.75		
Nominating	123.92		
Publication	499.05		
Educational	30.00	3,895.52	
Sectional Meetings			
Buffalo	333.86		
Hartford	565.25	899.11	
Chicago Convention			
Executive Salary	3,850.00		
Advertising	10,058.16		
Office and Traveling Expenses	14,144.73		
Exhibit Expenses—Rent, Power and Power Connections, Entertainment, etc	85,130.49	113,183.38	
Total Expenses		$215,530.41	
Balance—Carried to Surplus Account		27,139.30	
TOTAL			$242,669.71

News of the Chapters

STANDING OF THE CHAPTERS

IN the following tabulation there appears the relative membership standing of the 29 chapters and 2 groups of the Society as of March 1, 1927.

GROUP I		GROUP II		GROUP III	
1. Detroit	417	1. Hartford	141	1. Montreal	91
2. Cleveland	402	2. Lehigh Valley	131	2. Los Angeles	74
3. Chicago	395	3. Milwaukee	129	2. New Haven	74
4. Philadelphia	354	4. Golden Gate	116	4. Tri-City	72
5. Pittsburgh	330	5. Indianapolis	97	5. Washington	67
6. New York	272	6. Cincinnati	95	6. Rockford	64
7. Boston	246	7. Syracuse	89	7. Rochester	63
		8. St. Louis	85	8. Toronto	59
		9. Buffalo	63	8. Worcester	59
		10. North-West	56	10. Providence	54
				11. Schenectady	50
				12. Southern Tier	46
				13. Fort Wayne	40
				14. Springfield	33

There were 95 new and reinstated members for the month of February with 45 dropped for non-payment of dues and 9 for resignations and deaths, leaving a net gain for the month of 41, as compared with a net gain in February last year of 77.

The total membership of the Society on March 1, 1927, is 4436, while the total membership on March 1, 1926, was 3711, which shows a net gain for the past 12 months of 725.

GROUP I—Detroit with a net gain of 9, retains a lead of 15 over Cleveland. All of the chapters in this group maintain the same position and with the exception of Cleveland, show gains in membership.

GROUP II—Hartford with 141 still heads the group, with Lehigh Valley second, and Milwaukee a close third. The "triple tie" existing last month between Indianapolis, Cincinnati and Syracuse was broken by Indianapolis which shows a gain of 2 members. Cincinnati had no gain and Syracuse was unfortunate in having a net loss of 6 members. Buffalo in 9th place shows a gain of 5 members.

GROUP III—Montreal with 91 still sets the pace. The tie between Los Angeles and New Haven continues for another month, both chapters having 74 members. Tri-City, with a net gain of 5 members, advanced from 5th to 4th position displacing Washington. The other chapters in this group retain the same position as last month.

BOSTON CHAPTER

The seventh anniversary meeting of the Boston Chapter was held at the Massachusetts Institute of Technology on Friday, February 4, 1927. Dinner was served in the Walker Memorial at 6:15 p. m., after which about 100 members and guests listened to addresses of national director L. D. Hawkridge, who gave the high spots of the Washington, D. C., sectional and directors meetings; Prof. G. B. Waterhouse, of Technology; and Charles McKnight, Jr., of the International Nickel Co.

Dr. Waterhouse selected two recent papers for discussion, the first by M. Nicolet and published in the Revue de Metallurgique. The author gives a general survey of the instruments used for testing hardness of metals, giving special attention to the Rockwell Hardness Tester, which, he says, is becoming very popular in Europe. Much comparative data is given and he states that he prefers the 1/16-inch ball with the 100 kilograms weight for hardness figures up to B-95. Above that, he prefers the diamond with 150 kilograms weight. For case hardened work, he uses the diamond and 100 kilograms weight for depths less than 1/2 millimeter. With greater depths of case, he uses the 150 kilograms weight.

The second paper discussed was that recently presented to the American Society for Testing Materials, by O. B. Shultz, engineer of tests for the Lima Locomotive Works, Inc., entitled "*Some Defects which have been found in Large Carbon Vanadium Forgings.*" Mr. Shultz gives a very comprehensive discussion of the quality of carbon vanadium forging steel as influenced by (a) the manufacturing process, (b) forge shop practice and (c) heat treatment. Speaking of forging, he states that in the winter, the billets should be brought into the warm shop at least 24 hours before they are placed in the furnace. The best practice would be to preheat to 1000 degrees Fahr. at a rate not exceeding 150 degrees Fahr. an hour and then to transfer to the forge furnace and raise to 2100 degrees Fahr., soaking for a sufficient length of time to insure uniformity of temperature. Cooling after forging should be in a bed of ashes to decrease the likelihood of cooling strains and cracks.

When heating for normalizing, the forgings should be supported several inches above the floor of the furnace to insure complete circulation of the hot gases to every part of the forging. The rate of heat application should be maintained constant and after the proper temperature, 1550-1600 degrees Fahr., has been reached, the parts should be held for at least one hour per inch of thickness of the largest section of the forging being treated. The cooling should be in still air protected from draughts and rain or snow. Steel manufactured, forged and heat treated according to directions laid down by Mr. Shultz will, no doubt, readily meet the specifications of the railroads and withstand the severe service demanded by steam locomotive operation. A series of excellent photomicrographs showing good and bad structures accompanied the paper.

The principal speaker of the evening was Charles McKnight, Jr., of the development and research department, International Nickel Company, who selected as his subject "Some New Developments in the Use of Nickel Steel". Mr. McKnight prefaced his talk with a brief history of nickel in steel,

mentioning the use of meteorites by Faraday in 1821, the introduction of nickel in armor plate about 1890, and by 1896, the use of nickel in parts for ordnance, machinery, bicycles and automobiles. Since the establishment of the development and research department in 1922, many new uses have been found for nickel.

The use of nickel in locomotive parts was particularly emphasized. For 25 years, most of the improvements in locomotives have been the accessories, but recently there has been a trend towards higher steam pressure with no increase in weight. This has lead to a demand for a stronger boiler plate with the result that a 3 per cent nickel steel has been adopted by some of the railroads which not only gives a steel 40 per cent stronger but one less subject to the embrittlement phenomena known as "Ageing" and "Recrystallization" caused by straining beyond the elastic limit at atmospheric and elevated temperatures, respectively. Mr. McKinght carefully outlined the manufacture and treatment of this plate and also spoke of the application of steels containing nickel to boiler tubes, staybolts, axles and side rods. For axles and other heavy forgings, a 3-½ per cent nickel steel with only about 0.15 per cent carbon is used with excellent results.

Speaking of nickel in castings, Mr. McKnight cited the cast steel locomotive frames with 0.18 per cent carbon and 3 per cent nickel which are showing very high physical properties. Used in gray cast iron, he said nickel in percentages of 0.10 per cent to 3.00 per cent refines the grain, increases the machinable hardness, increases resistance to wear, increases strength, reduces chill and eliminates porosity. It is, of course, necessary to control the other elements, especially silicon, within specified limits. At the conclusion of the meeting, Mr. McKnight answered many questions.

I. H. Cowdry, the first secretary, and six other charter members who organized the Boston Chapter on February 13, 1920, were present. Birthday greetings from Secretary "Bill" Eisenman were read during the meeting.

H. E. Handy.

CINCINNATI CHAPTER

Mr. T. Holland Nelson, metallurgist for the Ludlum Steel Company, Watervliet, gave one of his inimitable talks before the Cincinnati Chapter of the American Society for Steel Treating on the evening of February 3.

The properties and applications of Nitralloy, the new surface hardening steel developed by the Krupp Works of Essen, were discussed. This steel is capable of being surface hardened by treatment for some hours in ammonia gas at 915 degrees to 925 degrees Fahr. The case produced has a Brinell hardness of about 900 and has a maximum thickness of one millimeter. Parts may be heat treated in the usual way to develop great strength and toughness and then may be finished to size, niturized and assembled. The niturizing causes practically no alterations in dimensions and no distortion as no quenching is necessary.

Niturizing offers many advantages to the manufacturer of gears and other intricate parts where extreme resistance to wear and freedom from distortion during hardening are vital factors.

A long discussion followed Mr. Nelson's talk, which demonstrated the

great interest aroused among the gear and machine tool manufacturers that were present. It is rare indeed that both the speaker and his subject are so enthusiastically received.

S. P. Rockwell will speak at the next meeting to be held at the Engineers' Club, March 10, 1927. The subject will be the Dilatometer and the Dilatometric method for controlling the hardening of steel. This method of heat treating is coming into extensive use where extreme precision in heat treatment is required and will be of interest to all who are concerned with the heat treatment of dies, fine tools and the like. *E. M. Wise.*

CHICAGO CHAPTER

On Thursday, February 10, this chapter turned out a record breaking attendance to listen to Jordan Korp, of the Leeds and Northrup Company, talk on "Tools, Design, Heat Treatment and its Relation to Production."

Mr. Korp, in his droll, inimitable style, drives home facts in an uncontrovertible, entertaining manner; using the black board effectively in illustrating points under discussion.

An hour and twenty minutes of lively and profitable discussion followed, and a grudging adjournment was had at 10:20 with a great demonstration of appreciation.

To those chapters of our Society, who have not had Mr. Korp, we want to say: You will have missed much of great value until you secure him.

During our dinner we were entertained with lively, instrumental and vocal music by the Dixie Duo.

GOLDEN GATE CHAPTER

The January 12 meeting of the Golden Gate Chapter was held at the Athens Athletic Club, Oakland, and there was an attendance of about 35. At the technical part of the meeting which followed the dinner, there were two speakers, Karl Sinclair of the Bethlehem Shipbuilding Corporation who spoke on "Coal Situation—Alaska from Personal Observation", and Mr. Thurston, a member of Golden Gate Chapter, led a general discussion on heat treating.

The discussion by Mr. Sinclair was very interesting, although it did not deal directly, of course, with the general subject of heat treating. However, a heat treater is interested in coal supply which is important in the production of the steel which he uses. As Mr. Sinclair spoke fluently from personal experience gained in the coal districts of Alaska, there were many informing points brought out in his talk. One revelation to many of those present was the fact that there apparently is not any supply of coal in Alaska to speak of, which condition is contrary to the general belief.

Mr. Thurston took charge of the question box discussion which is an innovation in the Golden Gate Chapter which proves very successful. The five most important questions which were presented were assigned to members present at the meeting for discussion and report at the February meeting. Below is a list of the questions and the members to which the questions were assigned:

1—Compare Ni and Cr-Ni steels for carburizing purposes. Assigned to A. Naish.

2—Why is a high draw said to be beneficial for a high speed steel? Assigned to J. Coulter.

3—To what temperature must high-speed tools be cooled before drawing, and why? Assigned to O. Pringle.

4—Is a steel that is suited for leaf springs also satisfactory for coil springs? Discuss heat treatment for Cr and Cr-Va spring steels. Assigned to J. Gearhart.

5—At what minium temperature can ingot iron or low carbon steel be carburized when using ordinary commercial compounds? Assigned to J. Gumz.

C. R. Owens.

LEHIGH VALLEY CHAPTER

The regular monthly meeting of the Lehigh Valley Chapter was held in the Public Library at Easton, Pa., on Tuesday, February 8.

The meeting was preceded by an executive committee dinner meeting at the Elks Club in Phillipsburg with H. W. Dunbar, assistant general sales manager of the Norton Company, as guest.

Our chapter was highly privileged to witness the first public showing of a new motion picture film published by the Norton Company entitled "The Age of Speed". This film presents a most interesting and consecutive story showing how we have passed through the various stone ages, iron ages, etc., in the past and how we are now living in the age of speed.

The film points out the remarkable developments which have been made in speed of transportation, communication and in various types of production machinery and shows the indispensable part which has been played by grinding wheels and grinding machinery in making this development possible. The film also gives a very interesting outline of the methods used in manufacturing grinding wheels of various types.

After the showing of the film, Mr. Dunbar made a few opening remarks on the general subject of grinding wheels emphasizing both their use and their abuse. This opened up a very interesting discussion which brought out questions covering many phases of grinding problems.

The meeting was adjourned with a vote of thanks to both the Norton Company and Mr. Dunbar for their courtesy in affording us a very interesting and profitable evening.

F. R. Palmer.

NEW HAVEN CHAPTER

The regular monthly meeting of the New Haven Chapter was held on Thursday, February 10. The meeting was preceded by a dinner at the Hotel Bishop, and from the marked increased attendance, it surely seems as if this part of the meeting is surely here to stay.

Shortly before eight, the meeting was called to order, by the chairman, C. J. Sauer, in the Hammond Metallurgical Laboratory of Yale University. The chairman introduced F. J. Dawless, chairman of the membership committee, who gave a detailed account of the membership drive which closed the last of the year. The drive itself gave a 50 per cent increase in membership

to the chapter, and the chairman announced that a tie existed in the contest between W. P. Eddy, Jr., and W. G. Aurand, who were both awarded twenty dollars. The third prize of ten dollars was awarded to C. J. Sauer. All three prizes were won by members of the executive committee, although every member of the chapter was eligible.

After a short business session, the chairman introduced the speaker of the evening, Hugh Rodman, president of the Rodman Chemical Company, Verona, Pa., who spoke on Carburizing Materials. This subject proved very interesting, and from the amount of discussion following the meeting it was the unanimous opinion of all present that this meeting was one of the best ever held by the New Haven Chapter which speaks well for the program committee.

The chairman next brought up the monthly question for discussion which was, "We all known that steel which has been chilled from cold weather will break quicker under a severe strain or shock than a piece of steel whose temperature is, say, approximately 60 to 70 degrees Fahrenheit." This caused considerable discussion and proved very interesting for everyone.

The attendance prize donated by E. C. Richardson was won by L. G. Saunders. The only stipulation, put on the winning of this gold pencil by Richardson, was that he hoped it would not be won by some steel salesman to go out and write steel orders with his donation.

Bridgeport was well represented at this meeting which shows the boys are on the job. More power to you. Keep the good work up. *W. G. Aurand.*

NORTHWEST CHAPTER

The February meeting was held Tuesday evening, February 15, at which J. P. Gill of the Vanadium Alloys Steel Company gave a talk on High Speed Steel. The first part of the program consisted of two reels of movies which showed the method of melting, pouring, and forging high speed steel.

Mr. Gill then gave the history of high speed steel and showed how the composition varied from the time Mushet discovered the self hardening steel to the present time. Each element was considered separately as regards the effect on the properties, method of heat treatment and amounts which give most satisfactory results for various types of work.

After discussing the composition of high speed steel, Mr. Gill took up the structure as seen under the microscope, from the ingot as cast to the finished product, showing clearly what changes take place during the forging operation. He next showed the effect of heat treatment on the structure in which he gave the effects both of temperature and time at temperature. This illustrated very clearly the fact that the two factors, temperature and time, both have to be taken into consideration in the heat treatment.

Mr. Gill next discussed various failures commonly met with and the type of fracture ordinarily associated with these failures. His large display of samples showing various failures and effects due to heat treatment was very well arranged to bring out more clearly the topics covered in the discussion.

This was one of the largest meetings this year and shows the great interest of the members in tool steels. Mr. Gill is to be complimented on the talk that he gave, which should be of great benefit to every one present.

L. J. Weber.

PHILADELPHIA CHAPTER

The January meeting of the Philadelphia Chapter was held on January 28, 1927, at the Engineers' club.

This meeting was attended by more than one hundred and seventy-five members and guests. This attendance again proves the interest that is being shown in the work being done by the chapter.

The first paper of the evening was one on the subject of chromium plating. It was presented by a practical man who is doing splendid work at the Frankford Arsenal in Philadelphia. Mr. Scott demonstrated his paper by means of splendid examples of plated work on gages, punches, etc. The interest taken in his paper was shown by the lengthy discussion which followed its reading.

The discussion brought out many interesting things such as power consumption, electrolytes, anodes, etc. Mr. Scott particulary brought out in the discussion the value of time and current regulation. It is hoped that more chapters will ask Mr. Scott to read his paper since the subject is of vital importance and interest.

The second paper of the evening was in the nature of moving pictures made at the Heppenstall Forge and Knife Company and showed the manufacture of die blocks, and other products. It was discussed by Mr. Succop, the metallurgist of that company.

The Philadelphia Chapter is again planning the issuance of a Year Book for 1927 and 1928. This feature of the chapter's activities has become very important and proven of value especially concerning the metallurgical educational work carried on by the chapter at Temple University. Any chapter officer and member of the Society in general who may be interested in this work may receive a copy of the Year Book for 1926-27 by addressing the secretary, A. W. F. Green, 407 Shoemaker Road, Elkins Park, Pa.

A. W. F. Green.

PITTSBURGH CHAPTER

The Pittsburgh Chapter held its February meeting on the evening of the 3rd.

There was a good attendance at the dinner which was served in the Bureau of Mines Restaurant previous to the meeting.

Chairman W. H. Phillips called the meeting to order at eight o'clock in the auditorium of the U. S. Bureau of Mines Building.

After the usual short business session, the speaker of the evening, F. R. Palmer, metallurgist of the Carpenter Steel Company, Reading, Pa., was introduced.

The title of Mr. Palmer's talk was, "Giving Steel Tools a Chance".

In introducing his subject, Mr. Palmer said that his talk would be based on the text that "hardened steel tools have just so much strength dependent

upon analysis, quality and heat treatment and when the total of all forces (internal and external) exceed 100 per cent, they break''. He defined quality as being determined by purity of ingredients, clean in respect to non-metallics and uniform in respect of one bar of the same steel to another.

He then proceeded with the aid of lantern slides to point out the many ways that these internal forces are brought in steel tools.

He first took up the very important part that tool design plays upon the strength of the tool and especially drawing attention to the tools of unbalanced sections, that is tools having both thick and thin sections. As an illustration a forming tool which had both thick and thin sections was shown and it was explained how this danger resulting from the unbalanced sections in heat treatment was surmounted by drilling holes in the proper places in the thick sections thereby tending to equalize the cross-sectional thickness in different parts of the tool. The danger of sharp angles and angular keyways was also pointed out.

After pointing out some of the dangers that can be introduced during forging of a tool, the speaker took up machining strains and showed by photo-micrographs how the immediate surface was injured by various machining operations especially noting prick punching because it generally is done at or near a working edge.

He gave an interesting and detailed account of a carriage bolt die that as made under adverse methods would stand up when soft steel was used with which to make the bolts but that the die would not stand up when a harder steel was used. This difficulty was entirely overcome by changing the method of shaping the die.

Mr. Palmer then described the ''fish scale'' structure in high speed steel which he said was brought about by reheating a previously quenched tool to a temperature equal to or higher than the first heating of over 2000 degrees. This ''fish scale'' structure can be broken up by forging between heatings.

He next gave a very clear description of the danger of quenching in the critical temperature zone.

This was followed by an interesting comparison of drawing temperatures at various lengths of time.

Lastly, but just as important, was the subject of abrasive hardening and grinding checks and cracks. This was well illustrated and showed very forcibly what injury carelessness or ignorance in this operation can bring about.

In closing Mr. Palmer made an earnest plea that the heat treater be provided in his department with equipment and devices capable of just as much precision and refinement of operation as the machinist and tool maker is in his.

An open discussion of the various phases of this talk was entered into with much interest by the audience and, finally, the meeting was adjourned with a rising vote of appreciation to Mr. Palmer for his very able and most interesting talk.

Harry A. Neeb, Jr.

SYRACUSE CHAPTER

On Friday, February 18, 1927, J. V. Emmons, of the Cleveland Twist Drill

Company, addressed the Syracuse Chapter on "Annealing of Tool Steel." Somewhat apologetic for speaking on this subject in the city where probably more tool steel is annealed than in any other city in the country, the speaker, nevertheless, gave us much interesting information.

There are three reasons for annealing, namely, to place the steel in the best condition for machining, to refine the grain left from the forging operation so that the steel may be successfully hardened; and to improve the cutting quality of the steel.

The problem of best machinability is a complicated one. A steel having a Brinell of 196 may be more difficult to machine than another steel with a Brinell of 228. A steel which will turn beautifully may be very poor for milling. These facts are more readily understandable when the microstructure of the steel is examined. Large plates of cementite in lamellar pearlite when traversed by a cutting edge are broken up into sharp cornered particles which have an abrasive action on the cutting edge; a steel in this condition is difficult to machine. However, if the cementite plates are agglomerated into rounded particles the steel will be less difficult to machine. Since completely spheroidized steel is in the best condition for turning but in the worst condition for threading, a compromise must be adopted and the annealing so performed as to leave the cementite in the steel about 30 per cent lamellar and 70 per cent spheroidized.

Tool steel as it comes from the forging operation usually contains large cementite grain boundaries, and if the steel were hardened from this condition, fire-cracking would probably take place. The annealing operation refines the grain and thus lessens the danger of fire-cracking. The temperature at which the steel is annealed must be high enough to break up the grain left by the forging. The time at the annealing temperature should be just sufficient to heat through the piece thoroughly. The rate of cooling from the annealing heat determines the finished structures. If the rate is fairly rapid, such as air-cooling, the structure will be sorbitic; if somewhat slower, pearlitic; if still slower, partially spheroidized; and if extremely slow, completely spheroidized.

A decarburized surface or "bark" is frequently found on annealed tool steels and causes difficulty not only in hardening but also in machining. The loss of carbon at the surface is due to the presence of some active oxidizing agent in contact with the steel at high temperatures. These oxidizing agents may be oxygen of the air, carbon dioxide, or mill scale, and the avoidance of bark is more or less of a problem on every annealing job.

Another difficulty which is sometimes met with in annealing—nowadays, to a great degree less than in the "good old days"—is the precipitation of graphite. This may be due to heating for a very long time at a temperature just below the critical, or by too slow cooling from a temperature above the critical.

One other difficulty met with in annealing is coarse grain due to overheating. Sometimes this overheated structure may be refined by a normalizing and annealing treatment, but sometimes the grain can be refined only by mechanical work.

In applying these theoretical considerations to the practise of annealing we must supply means for uniform heating and control of the cooling. For close control of the cooling rate, it is necessary that the steel be annealed in small batches. Annealing in lead has been found to work out very satisfactorily at the Cleveland Twist Drill plant for small forgings. The lead pots are about 28 inches x 15 inches and about 15 inches deep. From 200 to 400 pounds of forgings are placed in a heavy mesh basket and the basket with its load is forced down below the surface of the lead in the bath. About one hour is required for heating and soaking the forgings. Alongside the lead pots are a series of cooling pits; one for very slow cooling has a cast iron shell with a lining of silocel or a similar brick; one for medium cooling has a cast-iron shell lined with fire-brick; and one for fairly rapid cooling has only the cast iron shell. At the end of the heating, the operator removes the basket from the lead pot and deposits it in one of the cooling pits or the other depending on the structure desired in the finished product. This company has found that by means of this lead pot annealing, they can get a greater production with less labor cost.

The annealing of alloy steels is a different problem from that of straight carbon steels. The alloy steels do not form lamellar pearlite and therefore slow cooling is necessary to secure the proper growth of the cementite particles. Graphitization is promoted by nickel and silicon and practically prevented by small amounts of chromium.

In conclusion, the speaker advised small users to have their steel annealed by the manufacturer, unless they made forgings, whereas it is probably better for large users to do their own annealing. *S. P. Peskowitz.*

WORCESTER CHAPTER

The Worcester Chapter held its February meeting on the seventh at Baratti's Restaurant, 40 Pearl St., Worcester, Mass.

Sixty members and guests were present to enjoy the dinner and to hear Professor H. F. Moore (in charge of the Investigation of The Fatigue of Metals at the University of Illinois) talk on: "What Happens When Steel Fails by Fatigue?"

Professor Moore's talk was very enlightening and clearly illustrated causes of failure and development of the theory of the fatigue of metals. A brief outline of this talk and discussion follows:—

Cohesive forces which produce great strength in certain materials were illustrated by the professor who, lifting a pointer by one end, showed that the other end followed. The physicists claim the strength of materials should be much greater than they actually are. Engineers finding a strength of 50,000 pounds per square inch where the physicists claim 1,000,000 pounds per square inch. Explanation of this is probably that all the atoms of a material are not doing their duty. This could be illustrated by a wire screen where a single strand of wire will have a certain strength, but the strength of the screen would not be equal to the strength of a single strand multiplied by the number of strands. In fact, far below it.

To compute the strength of materials most people use formulas assum-

ing the materials they are testing to be uniform. In determining the elastic limit we assume that the distortion is proportional. The commercial tests for elastic limit are usually inaccurate. In fact, the professor was not sure but that the elastic limit was obtained with one pound stress.

Fatigue of metals first became known when the first car was run on rails. The live axle of the car broke due to fatigue without any warning. This led to tests of fatigue failure of steel. The fatigue strength of a metal is best determined by actual test in a testing machine designed to produce a rapid succession of measurable stresses.

For steel and iron the Brinell hardness and the tensile strength seem to be fairly good indications of the fatigue strength. For nearly all metals tested there seems to be a fatigue limit, or endurance limit, below which the metal will withstand an indefinitely large number of stresses.

Failure of steel never occurs simultaneously over the whole of a surface; it is always progressive. In ordinary tensile tests of steel, failure occurs so rapidly that its course cannot be followed. Under stress, repeated many thousands of times, failure spreads rather slowly, so slowly, that the progress of the crack may sometimes be followed. The word progressive failure should be used to indicate this type of failure. This fatigue failure of metals seems to be actual tearing apart of the particles of metals, it usually occurs at stresses below the elastic limit, but sometimes stresses above the elastic limit may be repeated hundreds of millions of times without causing failure. The progress of fatigue failure may be compared to the progress of a very small hacksaw cut. The damage done by a spreading crack is confined to an extremely narrow area and the properties of the adjacent metals do not seem to be changed.

The explanation of fatigue failure starting, as it does, at stresses far below the tensile strength of the metal, is that actual metals are not homogeneous, and have many minute areas of weakness.

Under a single load the average stress of metal is developed, under repeated loading a crack may start at some one of these areas of weakness, and since the crack is itself a source of weakness, there is a strong tendency for it to spread.

Stress raisers which cause failure are due to rough surface, such as file marks and sharp corners. A large per cent of the localized stress failures are due to improper design. Screw is a good example of a stress raiser. Hardening cracks are excellent stress raisers. In heat treating to improve the endurance limit, laboratory tests show that carbon steel is as good as alloy steel, but under shop conditions of heat treating the alloy steels are more nearly foolproof. *C. G. Johnson.*

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